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SDR TECHNIQUES TO DECODE SATELLITE BEACONS

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Telecommunications and Computer Engineering

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DEPARTMENT OF INFORMATION SCIENCE AND
TECHNOLOGY

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ABSTRACT

The advent of a new era of satellite communications brings with it a paradigm shift, a paradigm of reconfigurable receivers in software. Platforms like GNU Radio are therefore gaining preponderance. This revolution in these essential areas will allow for a more democratic area of communication in the future but will also act as a platform for more specialized study by users of this emerging technology.

GNU Radio is an SDR platform that allows the construction of receivers for all types of receivers, with different types of modulations.

In 2018, the QO-100 satellite was launched into a geostationary orbit. This satellite contains transponders that can be accessed by radio amateurs and other people and institutions. Of particular note are the beacons it has for communication with SSB modulation and a beacon for sending multimedia content.

It was then suggested that a project be created in GNU Radio that could receive, demodulate and decode information transmitted by the QO-100 satellite, especially information coming from the SSB beacon and multimedia beacon. To receive the signal, an earth station was built, consisting of a coaxial cable antenna and Hack RF One, there is also an optional DX Patrol component.

Keywords : GNU Radio, SDR , Satellite Communications, SSB, APSK, QO-100.

RESUMO

O advento de uma nova era de comunicações por satélites traz com ela uma mudança de paradigma, um paradigma de recetores reconfiguráveis em software. Plataformas como GNU Radio estão por isso a ganhar preponderância. Esta revolução nestas áreas essenciais irá permitir no futuro uma área de comunicação mais democrática, mas irá também agir como plataforma para mais estudo especializado por parte dos utilizadores desta tecnologia emergente.

GNU Radio é uma plataforma SDR que permite a construção de recetores para todo o tipo de recetores, com tipos variados de modulações.

Em 2018 foi lançado para um orbita geoestacionária o satélite QO-100. Este satélite contém os transponders que podem ser acedidos por radioamadores e outras pessoas e instituições. De particular nota são os beacons que possui para comunicação com modulação SSB e um beacon para enviar conteúdos de multimédia.

Foi então sugerido que se fizesse um projeto em GNU Radio que conseguisse receber, desmodular e decodificar informação transmitida pelo satélite QO-100 em especial informação provenientes do SSB beacon e multimédia beacon. Para receber o sinal uma estação terrena foi construída, composta por uma antena cabo coaxial e Hack RF One, também há um componente opcional, DX Patrol.

Palavras-chaves: GNU Radio, SDR, Comunicação Satélites, SSB, APSK, QO-100.

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LIST OF ACRONYMS

ADC - Analogue to Digital Converter
AGC - Automatic Gain Control
AMSAT- Amateur Satellite
AMSAT-DL - AMSAT Deutschland
APSK - Amplitude and Phase-Shift Keying
ASK - Amplitude-Shift Keying
ATV - Analogue Television
BER - Bit Error Rate
BPF - Band Pass Filter
CMOS - Complementary Metal–Oxide–Semiconductor
CPU - Central Processing Unit
DATV - Digital Amateur Television
DRA - Driver Amplifier
DSP - Digital Signal Processing
DSP - Digital Signal Processors
DVB-S2 - Digital Video Broadcasting - Satellite - Second Generation
EME - Earth-Moon-Earth
FEC - ForwardError Correction
FET - Field-Effect Transistors
FIR - Finite Impulse Response Filter
FPGA - Field Programmable gate arrays
GEO - Geostacionaryorbit
GMSK - Gaussian Minimum Shift Keying
GNSS - Global Navigation Satellite System

GPP - General Purpose Processors
GPS - Global Positioning System
HBTs - Heterojunction Bipolar Transistors
I/Q - In-Phase Quadrature elements
ITU - International Telecommunication Union
LEO - Low Earth Orbit
LNA - Low Noise Amplifier
MELCO - Mitsubishi Electric Corporation
MEMS - Micro-Electro-Mechanical Systems
MEO - Medium Earth Orbit
MF - Multi-Frequency
MMSE - Minimum Mean Square Error
NB - Narrow Band
PFB - Polyphase Filter Bank
PLL - phase locked Loop
PMT - Polymorphic Types
PSK - Phase-Shift Keying
QAM - Quadrature Amplitude Modulation
QARS - Qatar Amateur Radio Society
QPSK - Quadrature Phase-Shift Keying
RF- Radio Frequency
RMS - Root-Mean-Square
Rx - Receiver
SDR - Software-Defined Radio
SoC - System on Chip
SPC - Serial to Parallel Converter
SPS - Sample Per Symbol
SSB - Single-Sideband Modulation
TED - Timing Error Detector
TRF - Tuned Radio Frequency Receiver

TT&C - tracking telemetry and control

Tx - Transmitter

WB - Wideband

LIST OF SYMBOLS

$\Delta\varphi_i$ - angle between the cartesian coordinates

r_n – signal input

H_{LF} - loop filter transfer

$\begin{smallmatrix} I \\ Q \end{smallmatrix}$ - In Phase and quadrature vector

U_d – input of loop filter

U_f – output of loop filter

g_n – gain of a signal

p_n – average power of a signal

x_n – input power of a signal

y_n – signal output

α – argument

P – Position of a constellation point

R – Reference Value

a - Primitive root of a Galois Field

m – Integer of the relation between sampling frequency and of the IF frequency

n – point on a constellation ring

r – radius of constellation rings

s – s-domain representing complex frequency from Laplace Transform

τ - speed taken to respond to a step input of a first order, linear time invariant

φ - angle of desphazement

1 Introduction

1.1 Introduction

In this first chapter it will be presented a motivation for the theme of this dissertation, to introduce the topic. Besides that, this chapter will contain the Context, putting the theme of this thesis in a frame of knowledge in this area (satellite telecommunication), Goals that will give this thesis a practical content besides that of theory, and Methodology of this project so that the experiments used in this project can be replicated. The theme of this thesis will be the planning and construction of a receiver or modem using Software Defined Radio, that can decode information given by an artificial satellite namely a multimedia and SSB beacons.

1.2 Context

In the modern-day, satellite communications had been undergoing significant developments and advancements. A lot of technologies have been integrated into this form of communication such as 5G, GNSS and other. This technology has also evolved to be more in tandem with sustainability paradigm, by adopting a small satellite revolution and market competition to provide global coverage of this technology. The next step will be the adoption of Software Defined Radio receiver for the reception of the satellite signals thanks to their modularity and low cost.

This dissertation will intend to comprehend the function of a receivers so that SDR techniques could substitute them in decoding a multimedia and SSB beacons. This project will make use of the geostationary satellite Es'hail-2, a joint project by the Qatar Satellite Company (Es'hailSat), the Qatar Amateur Radio Society (QARS) and AMSAT Deutschland (AMSAT-DL).

1.3 Motivation

As can be inferred, the cost of setting up a receiver or ground station for satellite communication can be prohibitively expensive, especially for smaller organizations or even individuals [1]. As such the notion for constructing Software-Defined Radio (SDR) techniques to decode satellite beacons is to provide a flexible and cost-effective solution for accessing and decoding satellite signals. SDR enables the implementation of the receiver and demodulation functions in software rather than hardware, allowing for easier customization and experimentation [2]. This is particularly useful for amateur radio enthusiasts and satellite hobbyists who need to track and decode signals from various

satellites for communication or scientific purposes, or even for companies and organizations that need to control cost. The use of SDR also enables the decoding of multiple beacon signals simultaneously, reducing the cost and complexity of traditional hardware-based solutions.

The motivation for constructing a receiver, in particular for the QO-100 satellite, is to provide a means for communication and experimentation in the amateur radio community. The QO-100 satellite, also known as Es'hail-2, is a geostationary satellite that covers a large portion of the Earth, making it an ideal platform for amateur radio communication [3]. The construction of a transmitter and receiver for this satellite allows amateur radio operators to engage in long-distance communication, experiment with new modulation techniques, and participate in the growing field of amateur satellite communication. This satellite also has a novelty for the radio amateur community that of a multimedia beacon, this beacon can be used for a great number of experiments that in the future could help to teach in more detail the area of satellite communications. Finally, the construction of a low-cost and easily accessible transmitter and receiver can help increase participation and engagement in the amateur radio community, fostering new interests and skills in radio communication.

1.4 Goals

The goals designed for this thesis are to investigate SDR techniques to receive, decode and treat signals from the QO-100 satellite namely the multimedia beacon. To achieve these goals, it will be needed to construct a SDR receiver in GNU radio.

1.5 Methodology

Due to the nature of the work in this thesis, to be able to realize this project, was designed a multi-parted plan. The first part of this plan will involve the construction of the ground station to achieve communication with the QO-100 satellite. The second part will involve the construction of a software defined radio to receive data from the satellite. The final part of this thesis will be the decoding of said data.

The construction of the ground station will involve the mounting of an antenna of 1.8 meters in diameter. This antenna will be pointed at a certain patch of the sky, since the satellite used QO-100 is in a geostationary orbit there is no need for a tracking antenna.

To be able to communicate with said satellite, its signal needs to be decoded. Since the satellite is open to be used by radio amateurs there is no need to know the codes to be able to talk with the satellite. The received signal will passthrough a Software Defined Radio built in an open-source platform, GNU radio.

The method used for getting information from the signal are by order, the receiving itself as the name pertains, it entails receiving the analogue signal; the demodulation of the signal, the part of this method that transforms the symbols of the signal back into bits; and finally, the decoding where said bits are translated into readable information.

2 State of the art

The following chapter will deal with literature review and the programs used in this project. This chapter will be a systematic examination of current published works in certain areas. First It will be explained a brief history of satellite communications and its basic functioning, then it will be provided a review of the function and the characteristics of Software Defined Radio and the application that uses it, GNU Radio. The second part of the state of the art will consist of literature review of a common receiver and its structure, so that the components can be understood and then substituted by software components, followed by a review of the bands that allow communication with a Geostationary Satellites, finally a review of the modulation scheme used in the QO-100, 8 APSK.

2.1 Satellite Communications

The use of satellites for telecommunications allows for coverage in remote and hard to reach areas, increasing reliability, security, and global connectivity. In 1940s there were proposals to use the moon to reflect radio signals to other parts of the world, this type of communication is called Earth-Moon-Earth communication or EME for short [4]. Although interesting this type of communication has a lot of disadvantages namely the impossibility of controlling the moons orbit to change its relative position to earth, the high changes of the moon's surface temperature from 120C to -170 C, but most important is the time needed for a signal to reach the moon (1.25 s) and coming back to earth. To overcome this the artificial satellite was created. The first ever satellite telecommunication was started by the launch of Telstar all the way back in 1962. In the present 61 years after the first launch of a telecommunication satellite, this former niche of communication has ballooned in such a way that is indispensable to modern society, putting great pressure in demand for more capacity and new services such as GNSS (Global Navigation Satellite System) a service that was born out of necessity for military needs but now is used throughout civil society [5].

A satellite is essentially a repeater, takes the signal from the earth and send it to another location. Seeing this technology more closely we have the main components that make the satellites work: an integrated receiver and a transmitter of radio signals [6]. The receiver works as a transponder to be able to change the frequency band from the original signal. The original signal, or the signal sent to space, is called, and represented by uplink frequency and is sent by the transmitter back to Earth and is called and represented by downlink frequency. These main components must be able withstand and survive the acceleration to orbit velocity (28000 km/h), besides that in space itself, they must be able to survive the extreme radiation and temperature differences. The satellite must be able to have a large operational life and have low mass so it can more easily reach orbit, and the satellite must be constructed with robust and lightweight materials in order to have high reliability.

A satellite system can be divided in 2 parts the propulsion system and the communication system. The propulsion system will include everything that puts the satellite into orbit and maintains it there, such as the main drive and rockets and thrusters as well, to make slight adjustments to the

relative position of the satellite [6]. Even a geostationary orbit, where an object appears motionless given the frame reference of an observer on Earth, needs correction in its orbit because of the gravitational pull of the moon and sun, causing the satellite to deviate its orbit one degree in direction north/south or east/west in a year. The other important system is the communication system which contains antennas and transponders to receive and retransmit signals, this system will also contain the TT&C or tracking telemetry and control, this communication link between the satellite and ground control will inform the latter of the position and orbit of the satellite as well as its systems health.

For communication satellites there are three primary types of earth orbit, Low Earth orbit, Medium Earth orbit and Geostationary orbit.

Low Earth orbit corresponds to a circular orbit from 160 to 200 kms above earth's surface, and have a period of about 90 minutes, this means that they change their relative position to earth quickly. To cover the entire earth at least 20 LEO satellites are needed.

Medium Earth orbit goes from 2000km to 35700 km, and its satellites are very much similar to LEO satellites in terms of functionality, although visible for a time and have higher footprint that comes to a disadvantage is the longer time delay given the altitude of the satellites.

Geostationary orbit is positioned above 35700 km earth surface and complete an orbit with a period of 24h. This means that the satellite will appear motionless to an observer on earth, in this orbit there is no need for tracking antennas since the satellites are fixed in a position on the sky.

These satellites need to operate in specific bands, in order to minimize attenuation and distortion of frequency. To allocate these frequencies we turn to the International Telecommunication Union (ITU). The bands available for this type of communication are the bands: L, S, C, X, Ku, Ka and V [7] .

Telecommunication via satellites is very prominent in today, they mostly rely in telecommunication satellites in geostationary orbit. They provide various types of services such as internet services, broadcasting services (radio and television) and data communication.

2.2 Software Defined Radio

SDR defines a collection of hardware and software technologies where some of the radio's physical layer processing are implemented through modifiable software. This type of radio employs reconfigurable software-based components for processing and conversion of digital signals. Unlike traditional radio communication systems, these radio devices are highly flexible and versatile [2].

This approach will bring many benefits for radio such as:

- Common architecture that allows new products to be implemented much quicker.
- Substitution of physical components will allow to reduce costs of development.
- Remote reprogramming that will allow bug fixes while the radio is in service reducing the operation and maintenance cost.

- New features that can be added without requiring major expenditures do the existing infrastructure.

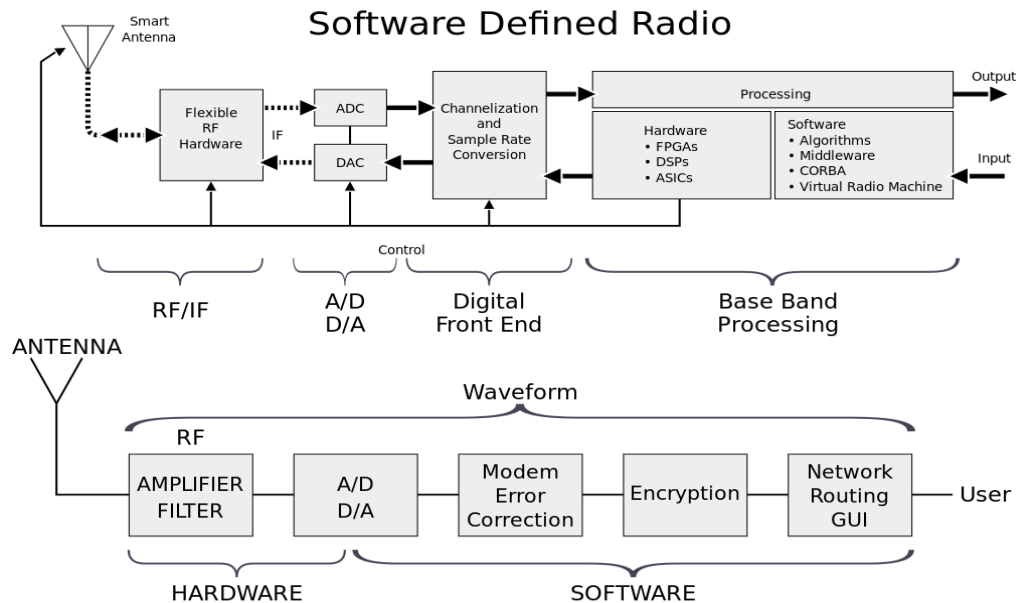


Figure 2.1 - Diagram of a Software Defined Radio

A typical SDR system consists of an analogue front-end and a digital back-end. This SDR platform operate over a large bandwidth over a great range of frequencies (DC-18 GHz) [8].

The platform is essentially comprised of an analogue front-end and a digital back-end. This back-end features a programmable gate array (FPGA), digital signal processors (DSP), general purpose processors (GPP), programmable System on Chip (SoC) and utilizes reconfigurable logic gates for different functions besides having other application specific programmable processors, and it is this features that allows new features to be added to the radio without a substitution of hardware.

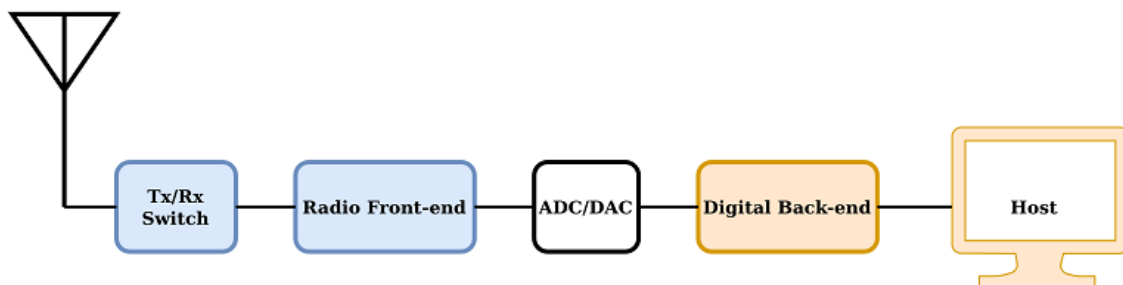


Figure 2.2 - Simple Diagram of a SDR

2.2.1 Boards

The architecture of a typical SDR platform consists of the boards: power, digital, time, receive (Rx) and transmit (Tx) modules [8]. The boards are connected using high speed cables:

Power board - supplies the power to the other boards.

Time board - gives stable clocks for the SDR system.

Receive board - is comprised of multiple independent receive channels. As previously seen the analogue signals received will be treated in amplifiers and downconverters as well as filters and ADC conversion to digital domain.

Transmit Board - just like the receive board it features multiple independent transmit channels. And each channel will be upconverter, filtered and amplified.

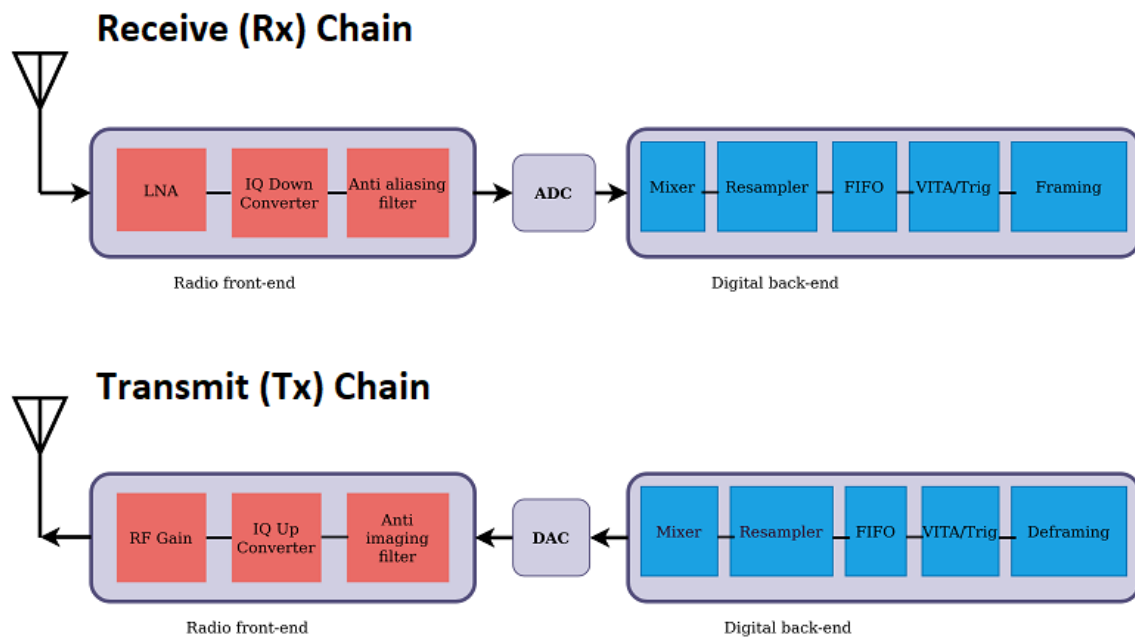


Figure 2.3 - Receivers and Transmitter Chains of SDR

2.2.2 Sample rates and resolution

In this system, to reconstruct the signal perfectly, the input signal needs to be sample at least twice the maximum input frequency, following the requirements of the Nyquist frequency, although rarely a signal can be reconstructed perfectly. The A/D converter to accommodate this

limit will need to have sampling frequencies of 3.6 Giga Samples Per Second- and 12-bit resolution as a maximum, although there is 8-bit resolution this resolution cannot provide a clean signal derived from excessive spurious emissions.

2.2.3 Gnu Radio

With the concept of SDR defined we now turn to apply that concept into a platform that allows us to design SDR models. That chosen platform is GNU Radio.

GNU Radio is a collection of software that when combined with minimal hardware, allows the construction of radios where the actual waveforms transmitted and received are defined by software. What this means is that it turns the digital modulation schemes used in today's high performance wireless devices into software problems [9]. Gnu Radio is used in a plethora of ways ranging from signal processing to radio astronomy, as such is used for hobbyists, academics, and even commercial applications [9].

This platform is based on blocks that can be variables or associated hardware features, these blocks are implement using as a programming language Python or C++, this also allows the user to create his own blocks, being this one of greatest asset to this platform. These blocks are organized into a flowgraph and are all connect to describe a data flow [9].

Gnu Radio can be used in a various way in different devices and operating systems, originally designed for Linux, GNU Radio now can be used in Windows, Raspberry Pi and other devices and operating Systems. As of today, GNU Radio comes with a graphical UI, GNU Radio Companion and GCR, which is a Python code generation tool. For analysing result Gnu Radio provides may plots, and data sinks for data visualizing and debugging [9].

2.3 Literature Review

In conventional analogueue technology there 3 main types of receivers [10].

Tuned Radio Frequency Receiver (TRF) were the very first receivers, they worked by receiving the incoming radio waves from the antenna and feeding them to a rectifying element and a headphone connected to it. This receiver can only detect amplitude modulation and is very insensitive due to lack of amplifiers, it receives signal from all transmitters at once but lacks frequency selection.

Superheterodyne receiver was designed as an improvement on TRF, that uses the receiver principle called Superheterodyne. It works in the beginning by a slight pre-amplification of the signal, with a tuned RF stage that amplifies a region of the frequency band of interest coming from the antenna [10], that then goes to a mixer, which mixes an internally generated superheterodyne frequency from an oscillator.

These receivers were ultimately very specialised, costly and lacking in adaptability. As such is very fortuitous to switch to a digital receiver so those weakness can be eliminated.

2.3.1 Digital receiver:

The next step in the evolution of receivers was the digital receiver, in these kinds of system, the receivers are digitalized and then processed in a computer chip. These receivers are dependent on the performance of the sample circuits and DSPs. These are the digital components that separate from analogue counterparts.

One of the main features of this technology is the RF distribution Function [11]. This function pertains to the digitalization of analogue RF inputs with analogue to digital Converters or ADCs. The digital receiver is comprised of 2 subsystems, a signal and power.

Although similar digital receivers aren't SDR. A digital receiver has at least some part of the signal processing is done digitally, a SDR receiver could have a large part, or all the signal processing chain implemented as software or reconfigurable hardware.

2.3.2 Demodulation - Phase and amplitude detection

One of the tasks the receivers need to do are the amplitude and phase detection, several techniques can be used to detect them. These two tasks are very important to detect and extracting information from a signal.

In the case of amplitude detection, it can detect and demodulate a signal with an amplitude modulation. The phase detection is used to determine the phase shift of a signal, this task is vital for demodulating signals that use phase shift in its modulation, APSK, PSK and even QAM. As an RF signal is polar in representation it can be decomposed into its Cartesian Representation [11], these individual I/Q components are digitized.

To extract the information from the phase they depend on algorithms and on the fact that between two successive samples ($y(t_i)$ and $y(t_i + 1)$) the amplitude and phase do not change significantly. To obtain it along with the information about amplitude the I/Q vector can be determined by the rotation algorithm.

$$\begin{pmatrix} I \\ Q \end{pmatrix}_{t_i} = \begin{pmatrix} \cos \Delta\varphi_i & -\sin \Delta\varphi_i \\ \sin \Delta\varphi_i & \cos \Delta\varphi_i \end{pmatrix} \begin{pmatrix} y_i + 1 \\ y_i \end{pmatrix}$$

Equation 2.1 - I/Q Vector

where $\Delta\varphi_i$ represents the angle between the cartesian coordinates of the components in relation to the initial vector. Finally, the following equation:

$$\Delta\varphi = \frac{2\pi}{m}$$

Equation 2.2 - Angle between the symbols

represents the phase difference between two samples [11].

With the detection of the phase and amplitude of the signal determined, our eyes must be focused on decoding. Since in wireless communication frames with headers have an important part to decode them, we have a technique called rotation headers. They involve the transmission of headers with properties representing modulation schemes and time offsets so that we can adapt to the received signal. One example of rotating headers is the technique of the Unique Word. A unique word, also known as a training sequence, is a predefined sequence of symbols that is inserted into the transmitted signal. This sequence is known to both the transmitter and receiver. When the receiver detects this known sequence, it can use it to estimate the channel's properties and adjust its demodulation parameters accordingly. The unique word method is valuable because it provides a reference pattern that the receiver can detect reliably. It helps the receiver distinguish between the actual data and the synchronization sequence, which aids in accurate demodulation.

2.3.3 Ku and Ka band

With the rapid increase of satellite communication and other similar technologies, the variety of frequencies that can be used has shifted to higher values. Although these higher frequencies band give access to wider bandwidth, they have some disadvantages such as degradation of signal due to atmospheric phenomena [7].

The bands now more commonly used for satellite communication are KU and Ka band. The Ku band has a bandwidth from 10 to 18 GHz and is quickly becoming more crowded. Because of that more services have come to the Ka band, with a bandwidth from 26 to 40 GHz. The Ka band is more susceptible to atmospheric absorption such as rain and atmospheric absorption which can affect signal quality and reliability.

In summary the Ka band operating at higher frequencies is more suitable for high-speed data transmissions and applications that need higher bandwidth. In contrast the Ku band is often used for more reliable and stable communications [7]. If we were to put receiving earth stations with the same size using the Ka and Ku band it could be seen a higher reflector gain for the Ka band, this reflector gain can be somewhat offset as seen previously by the loss of signal derived from atmospheric interference. This will mean that the carrier level output is identical for both bands.

In this project signal coming from the chosen satellite belongs to the Ku band.

2.3.4 Receiver structure

With analogue and digital receivers and bands operated by them now explained we can now turn into a structure of modern general receiver structure. Nowadays the receiver structure of an antenna has evolved to be composed of two main parts, the RF front end and a digital signal processing block.

Although there are many configurations for a satellite receiver in a ground station to receive a downlink signal, it generally can be designed as following. A signal coming from a geostationary satellite, when directly received by an antenna, needs to be pass through a downconverter. Afterwards it is filtered through a BPF, then passes through an LNA. The signal alongside with a local oscillator, is mixed and the components I and Q of the signal are separated, and each pass through an ADC [12] Even though these are the main components of a receiver, others can be added if needed such as phase shifters, attenuators, driver amplifier (DRA) and a serial to parallel converter (SPC), analogue to digital converters (ADC).

A critical component in communication systems the phase shifter controls the steerable communication links [13]. The shifter that is derived from the CMOS technology has various types such as switched delay or vector modulation. The shifter is composed of a 5-bit section incorporating high or low pass filter. Phase shifters can be designed using various technologies such as diodes, MEMS (Micro-electro-mechanical systems), or ferrite devices. The most common types of phase shifters are analogue and digital. Digital phase shifters, on the other hand, use a series of discrete phase states that are switched on and off to achieve the desired phase shift. They can provide very accurate phase shifting and are often used in phased array systems, where precise beamforming is required.

A Low Noise Amplifier (LNA) has the objective of amplifying low power signals without adding much noise or degrading the signal. LNA are typically the first active stage of a receiver system because its noise-gain performance affects the overall receiver's noise [14]. LNAs are typically designed using high-performance transistors, such as Field-Effect Transistors (FETs) or Heterojunction Bipolar Transistors (HBTs), to achieve low noise and high gain. They may also include other components, such as matching networks and filters, to optimize their performance.

A down converter, also known as a downconverter, is an electronic device that converts higher frequency signals to lower frequency signals. In the context of radio frequency (RF) communication systems, a down converter is used to receive and process high-frequency signals from satellites, radio transmitters, or other sources. These signals are typically in the range of several gigahertz (GHz) to tens of gigahertz, which can be difficult to process directly. A down converter reduces the frequency of the signal to a more manageable level, typically in the range of a few hundred megahertz (MHz) to a few gigahertz, where it can be processed more easily. This process is often necessary for signal amplification, filtering, and modulation/demodulation, which are required for the transmission or reception of RF signals. Downconverters are used in a variety of applications, including satellite communication systems, radar systems, and wireless communication systems. They are commonly used in radio and television broadcast systems to convert satellite signals to a lower frequency for distribution to households.

Filters are very important in the construction of the receivers because they allow to only pass select signals and can even cancel out noise. There are two main filters, band-pass and low pass filters. BPF, the band pass filter is component that only allows to pass a certain band of the signal without adding noise or distorting the signal [15]. The low pass filter is a component that allows only to pass signals bellow a cutoff frequency, while all other signals are attenuated.

A decimator is a receiver component that performs decimation. Decimation is a very important process that is essentially the process of reducing the sampling rate of a signal. Decimation can be explained as a two-step process, with an equivalent implementation that is more efficient [16]: first a reducing in the high frequency component with a digital lowpass filter and then the downsample.

Finally, ADC is component that end up converting analogue signals into a series of digital values.

If a SDR end up being created, all or a large part of these components need to be transcribed into processing block.

2.3.5 APSK modulation

The QO-100 satellite communicating signals are modulated using the APSK technique, with 8 bits [17].

APSK stands for Amplitude Phase-Shift Keying, and it is a type of modulation scheme used in digital communication systems. APSK is a hybrid modulation scheme that combines elements of amplitude modulation (AM) and phase-shift keying (PSK) to efficiently transmit data over a communication channel. In traditional PSK, the information is conveyed by varying the phase of the carrier signal, while in AM, the information is conveyed by varying the amplitude of the carrier signal. APSK takes advantage of both amplitude and phase variations to achieve a higher level of spectral efficiency and better performance, especially in the presence of noise and channel impairments. APSK modulation is commonly represented on a constellation diagram, where the points on the diagram correspond to specific combinations of amplitude and phase values for the carrier signal. The different points in the constellation represent different symbols or information bits. The modulation schemes come in various configurations, typically denoted as "APSK-X-Y," where "X" represents the number of symbols in the inner ring of the constellation diagram (usually corresponding to higher amplitude values), and "Y" represents the number of symbols in the outer ring (usually corresponding to lower amplitude values). These inner and outer rings are sometimes referred to as "shells."

The advantages of APSK modulation has over other type of modulations include spectral robustness and spectral and power efficiency. In terms of spectral efficiency, APSK modulation can achieve higher data rates compared to traditional modulation schemes by efficiently utilizing both amplitude and phase variations as discussed previously. The combination of amplitude and phase variations allows APSK to be more resilient to noise and channel impairments, leading to improved performance in challenging communication environments [18]. As for power efficiency, APSK can achieve good power efficiency since it can use different amplitude levels to represent multiple symbols, optimizing power usage.

APSK is commonly used in various digital communication systems, including satellite communication, wireless communication, and digital broadcasting, where efficient use of the available bandwidth and robustness to channel impairments are crucial factors. However, it is worth noting that as the modulation order increases, the system becomes more susceptible to noise and

other impairments, so a balance between spectral efficiency and robustness must be considered in practical implementations.

8-APSK modulation, also known as 8-Amplitude Phase-Shift Keying, is a specific configuration of APSK modulation. In 8-APSK, the constellation diagram is designed to have 8 distinct points representing different combinations of amplitude and phase values for the carrier signal. Each point in the constellation diagram corresponds to a unique symbol or group of information bits.

The 8-APSK constellation diagram typically arranges the points in two rings, one inner ring, and one outer ring. The inner ring can consist of 1 up to 4 points, the outer ring consists of 4 to 7 points. The phase values of the points are chosen in such a way that they are equidistant from each other around the circle, ensuring uniform angular spacing [19]. The points on the rings can be given by:

$$X = \begin{cases} r_1 e^{j(\varphi_1 + \frac{2\pi}{n_1}k)} & |k=0,1,\dots,n_1-1 \\ r_2 e^{j(\varphi_2 + \frac{2\pi}{n_2}k)} & |k=0,1,\dots,n_2-1 \\ r_N e^{j(\varphi_N + \frac{2\pi}{n_N}k)} & |k=0,1,\dots,n_N-1 \end{cases}$$

Equation 2.3 - APSK Constellation Points

Where r_N represents the radius of a concentric ring, φ_1 the angle of the phase and n_N the number of points per ring, this characteristic allows for different configurations of the constellation depending on the needs of the users [20].

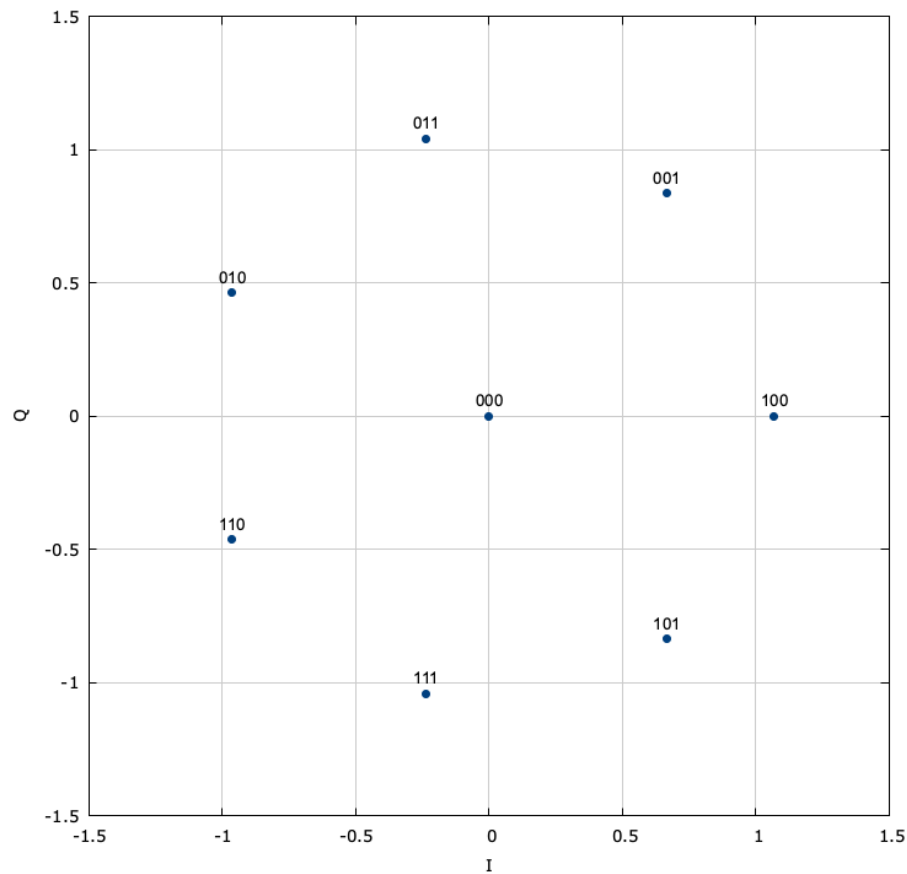


Figure 2.4 - 8 APSK Constellation

2.3.6 SSB

Single Sideband (SSB) signals are a type of amplitude modulation (AM) technique used in radio communication. Unlike traditional AM signals, SSB signals are more efficient in terms of bandwidth and power usage, making them popular in long-distance and high-frequency (HF) radio communication.

This type of signal as the name implies utilizes only one of the two AM sidebands [21]. This gives the signal a smaller bandwidth, using in average less power in the transmission of the signal, this is favorable to satellite communications or other communication through high distance.

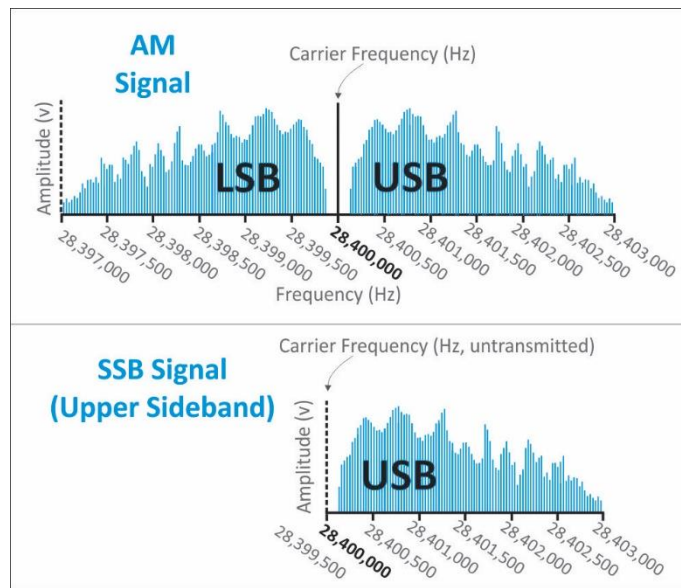


Figure 2.5 - SSB Signal

There are two approaches to eliminating one of the sidebands, one is the filter method and the other is the phasing method. The phasing method uses the Hilbert Transform that can be used as a block in GNU Radio. The discrete Hilbert Transform is a process by which a signal's negative frequencies are phase-advanced by 90 degrees and the positive frequencies are phase-delayed by 90 degrees. This results in a signal with no negative frequencies. Also, the magnitude of the frequency component in the complex signal is twice the magnitude of the frequency component in the real signal [22].

2.3.7 Resume

By joining all the knowledge above and resuming, a few conclusions can be made:

- Analogue and other types of receivers besides costly are not modular or much customizable as there are too much specialized. A SDR receiver could offset most if not all these problems.
- For receiving a satellite signal, it must pass first through an antenna and then a LNA so that the high frequencies travelling with the signal can be downconverted.
- If is needed to decode a satellite signal, first its phase must be locked in the case of amplitude detection, the phase detection is used to determine the phase shift of a signal, this task is vital for demodulating signals that use phase shift in its modulation, APSK.
- If we aim to construct a SDR the components of a normal receiver must be known: BPF, LNA, local oscillator, phase shifter, attenuator and many more. These components have or can be made to have a simulated component in GNU Radio.
- The 8-APSK modulation commonly used in various digital communication systems, including satellite ere efficient use of the available bandwidth is crucial. The 8-APSK constellation diagram typically arranges the points in two rings, one inner ring, and one

outer ring. The inner ring can consist of 1 up to 4 points, the outer ring consists of 4 to 7 points.

- In satellite communication two band are used, Ka and Ku the Ka band is more susceptible to atmospheric absorption such as rain and atmospheric absorption, and although the Ku band is more crowded the satellite signal of the QO-100 belongs to it. Ku band has a bandwidth from 12 to 18 GHz.
- The SSB modulation is a relatively speaking a simple, robust modulation used in voice communications for the QO-100 satellite.

3 QO-100

Launched in 2018 from the Kennedy Space Center, this satellite will boost broadband delivery, broadcasting and global connectivity in Qatar, the entire region and beyond. Es'hail-2 was manufactured in Japan by MELCO (Mitsubishi Electric Corporation). Es'hail-2 has Ku-band and Ka-band capabilities and support TV distribution, telecoms and government services to strategic stakeholders and commercial customers who value broadcasting independence, interference resilience, quality of service and wide geographical coverage. Its currently in a geostationary orbit at 25.9° East.

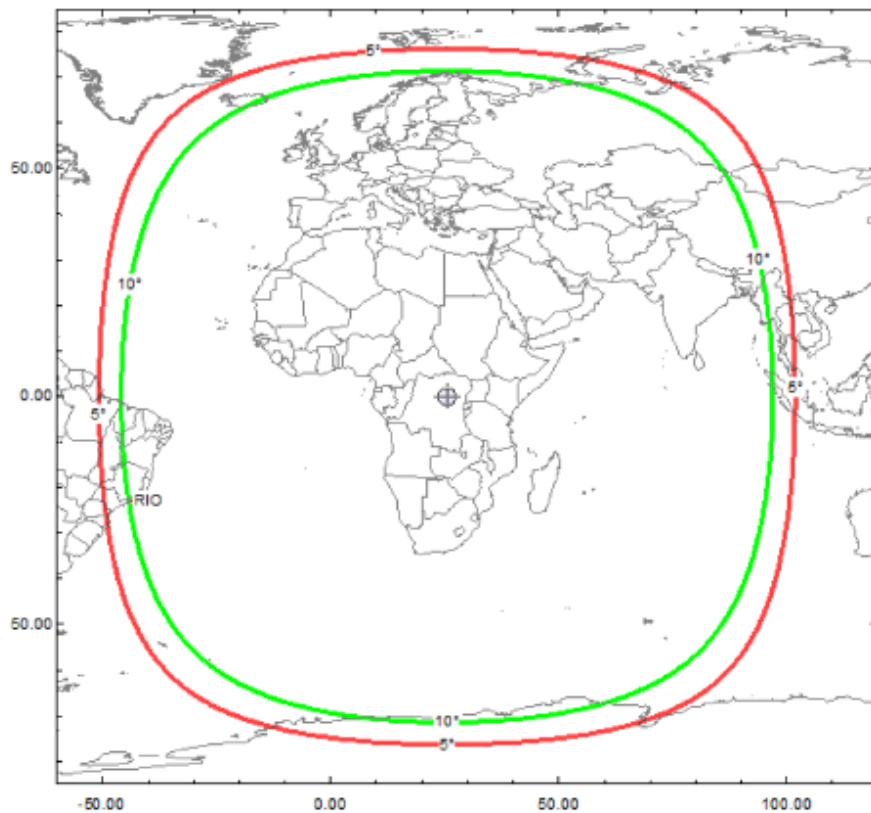


Figure 3.1 - QO-100 Footprint

This satellite carries two amateur radio transponders: narrowband and Wideband. The operating frequencies for uplink and downlink are available as pertained int the figure 3.2. Besides, the QO-100 is the first amateur radio satellite with a Wideband transponder for DATV operation.

Frequencies narrow band (**NB**) transponder (bandwidth 250 kHz):

	lower end	upper end	polarisation
Uplink	2400.050 MHz	2400.300 MHz	RHCP
Downlink	10489.550 MHz	10489.800 MHz	vertical

Frequencies wide band (**WB**) transponder (bandwidth 8 MHz):

	lower end	upper end	polarisation
Uplink	2401.500 MHz	2409.500 MHz	RHCP
Downlink	10491.000 MHz	10499.000 MHz	horizontal

Figure 3.2 - QO-100 Transponders characteristics

3.1.1 Transponders

The two transponders available to the satellite operate in the following sequence: reception, filtering, amplification, and retransmission.

In the NB transponders, once the signal received, filters are used to narrow the frequency range. In the WB filtering the frequency range is not narrowed or expanded, and in both unwanted signals and noise are discarded. Amplification, the following step, is where the filtered signals are then amplified to boost their strength so that they can be able to reach the intended destination. Final step is retransmission, after amplification the transponders there is a retransmission of the signals back into space to be received in ground stations or other sites.

3.1.2 Narrow band transponder

The narrow band transponder is used for narrowband digital signals and analogue signals, within a specific narrow frequency range. The term "narrowband" refers to the small bandwidth used by the transponder, typically ranging from a few kilohertz to a few megahertz.

Narrowband transponders are advantageous in certain situations because they allow multiple transponders to operate in proximity without significant interference. Also, they are more immune to certain types of noise and interference compared to Wideband communication systems. However, one limitation of narrowband transponders is their lower data transmission rates compared to Wideband communication systems, being that Wideband systems can transmit more information in each amount of time due to their broader bandwidth.

Overall, narrowband transponders play a crucial role in various communication systems, especially in situations where the emphasis is on reliability, interference mitigation, and efficient use of limited frequency resources.

In the case of this satellite the guidelines and the plan for the narrowband transponder can be seen bellow.

Uplink Start [MHz]	Uplink End [MHz]	Downlink Start [MHz]	Downlink End [MHz]	total BW [kHz]	Description
–	–	10489,500	10489,505	5	Lower Beacon 10489,500 MHz, CW F1A 400Hz shift, + guard band
2400,005	2400,040	10489,505	10489,540	35	CW only
2400,040	2400,080	10489,540	10489,580	40	digimodes (500 Hz max. BW)
2400,080	2400,150	10489,580	10489,650	70	digimodes (2700 Hz max. BW)
2400,150	2400,245	10489,650	10489,745	95	SSB only (2700 Hz max. BW)
–	–	10489,745	10489,755	10	Middle Beacon 10489,750 MHz, 400 Bit/sec BPSK, + guard bands
2400,255	2400,350	10489,755	10489,850	95	SSB only (2700 Hz max. BW)
2400,350	2400,3575	10489,850	10489,858	7,5	Broadcast frequency 10489,855 MHz + guard bands
2400,3575	2400,365	10489,858	10489,865	7,5	Emergency frequency 10489,860 MHz + guard bands
2400,365	2400,490	10489,865	10489,990	125	mixed modes (2700 Hz max. BW) & special purpose (incl. contest)
–	–	10489,990	10489,997	7	Multimedia Beacon, 10489,9935 MHz, 8APSK, 7200 Bit/sec, + guard bands
–	–	10489,997	10490,000	3	Upper Beacon 10490,000 MHz, CW F1A 400Hz shift, + guard band

Figure 3.3 - Narrow Band Plan

3.1.3 Wideband transponder

A Wideband transponder is a communication device that operates with a significantly broader frequency range or bandwidth compared to narrowband transponders. It is designed to receive and retransmit signals over a wide range of frequencies, typically spanning several megahertz or even gigahertz.

Wideband transponders are highly advantageous in situations where high data transmission rates are essential, such as in broadband internet services, digital television broadcasting, and data-intensive applications, such as is the case for this satellite. They allow for

efficient utilization of the available frequency spectrum, enabling the transmission of large amounts of data in a relatively short period.

However, Wideband transponders can be more susceptible to interference, as they cover a broader frequency range, making them more vulnerable to adjacent channel interference and other types of signal degradation. Therefore, careful frequency planning and signal management are critical to ensure optimal performance in Wideband communication systems.

These operating guidelines and proposed band plan are designed to enable the most efficient use of the 8MHz wide transponder for all users. It is expected that these initial guidelines will be further developed after commissioning.

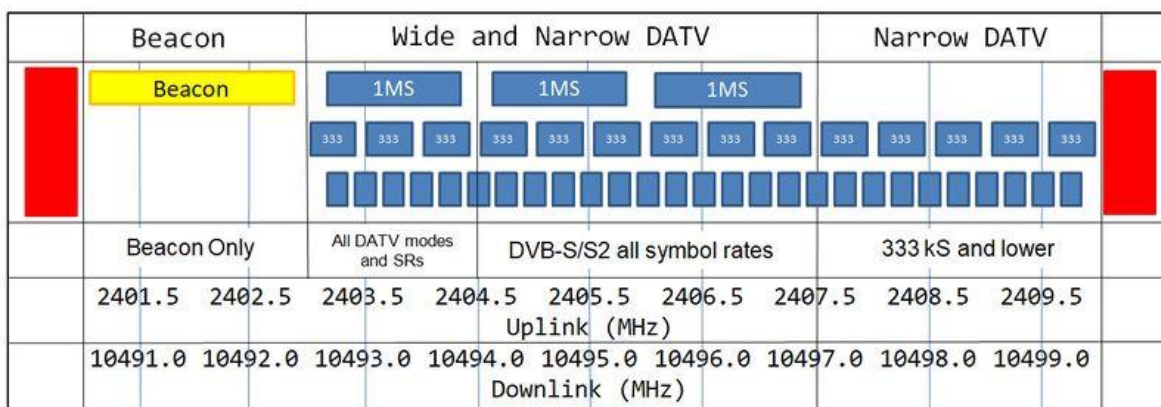


Figure 3.4 - Wideband Plan

3.1.4 QO-100 DATV Reception

QO-100 is the first amateur radio satellite with a Wide Band Transponder (WB) for DATV operation.

DATV (Digital Amateur Television) reception refers to the process of receiving and decoding digital television signals transmitted by amateur radio operators. Digital Amateur Television is an adaptation of traditional analogue amateur television (ATV) that utilizes digital encoding and modulation techniques for video and audio transmission.

DATV reception has become increasingly popular among amateur radio enthusiasts due to its higher video quality and improved resistance to signal degradation compared to traditional analogue ATV. It allows amateur radio operators to transmit and receive real-time video content, such as live events, presentations, and experiments, expanding the capabilities of amateur radio beyond voice and data communication.

However, it's important to note that DATV transmissions require more advanced equipment and knowledge compared to traditional analogue ATV.

The DATV beacon is currently transmitting a continuous loop to help users with reception and optimisation of the reception system.

The video beacon has the following parameters:

- 10492.50 MHz
- DVB-S2
- 2 MSym/sec
- QPSK FEC 2/3
- Rolloff 0.2

3.1.5 QO-100 High Speed Multimedia Beacon

With great importance to this project the QO-100NB transponder has a AMSAT-DL Highspeed Multimedia Modem” developed by Kurt DJ0ABR. This beacon transmits the following multimedia content:

- Narrow Band Transponder Activity
- Wide Band Transponder Activity
- DX Cluster Messages
- CW Skimmer
- AMSAT Bulletins
- APRS (planned)

The beacon also as the following settings [17]:

- Center frequency: 10,489,995 MHz
- Zero beat, SSB: 10,489,993.3 MHz
- Modulation: 8 APSK
- Symbol rate: 7200 bit/s
- HF bandwidth: 2700 Hz

3.1.6 File Transfer Format [23]

To be able to receive data from the satellite through the ground station it is needed to know how the data is sent and formatted from the satellite.

The information is divided into frames. This frame is on its whole composed of 258 bytes, 3 of them are used for the header and the rest 255 bytes of data are scrambled. The number of total bytes chosen for the frame (is important because it can be divided by 2 (129) and also by 3 (86) [24] . Therefore, we can convert it to QPSK and 8APSK symbols without any fractional remaining bits which makes calculations more efficient.

3.1.7 The header

The header composed of three bytes has the passive objective of having its symbols found, these bytes are not scrambled. As the phase is unknown for the modulation type available the symbols can be made to rotate by 8 in case of 8 APSK modulation. (For detection of the rotation value the “unique word” method is used as explained in the 2.2.4) If the header is detected then the rotation value is found and the whole frame is back rotated by this value resulting in the original stream (8 values for 8APSK) [24]. There is function to calculate the rotation available in constellation.cpp [25].

3.1.8 Data [26]

The data part of the frame is composed of 255 bytes. Of these only 219 bytes are used as payload of information, the other correspond to the frame counter (10 bits 0-1023) which does exactly what it pretends and its value is increase by one for each frame; frame status which gives information in 2 bits about the first last frame of a file, and other information dependent on the type of data; next it comes the frame the type that transmitted

- 1 ... BER Test
- 2 ... Image
- 3 ... Ascii File
- 4 ... HTML File
- 5 ... Binary File
- 6 ... Audio (i.e. Codec2)
- 7 ... User Info (Callsign, Locator...)

these 2 Bytes are added in front of the payload. Now we get 2 byte + 219 bytes = 221 bytes.

In the next step the CRC16 is calculated, over all 221 bytes. The two CRC16 bytes are added at the end, which results in a length of 223 bytes. These 223 bytes are fed into the Shifra-FEC function which generates 32 bytes of FEC information. The 32-byte FEC is added at the end. Now we got: 223 bytes + 32 bytes = 255 bytes. Finally, the fixed 3-byte header is added, and we got the complete frame of 258 byte ready to be sent convert bits to symbols according to the selected mode (BPSK, QPSK, 8APSK). (See functions in constellation.cpp) these symbols are then sent to the modulator, which in turn generates the audio samples.

When the receiver is designed and constructed, to be able to read the data sent from the satellite it needs to demodulate the signals samples to their corresponding symbols, convert the symbols into bits, de-scramble those symbols run the FEC and the Check and finally we have the payload.

4 Setting up the Groundstation.

The ground station that will be used for the reception of signal is composed by three elements. The antenna system that receives the signal proper and contains elements to treat it, the coaxial cable and the SDR equipment that allows the signal to be well received in the CPU and the CPU itself.

4.1.1 The antenna system

The antenna used or this project is a fixed parabolic antenna for the KU-band and is used to receive signals from geostationary satellites.

The dish of the parabolic antenna has 1.8m in diameter that can be used for downlink or uplink communication. In the current configuration it is only available the downlink communication. This parabolic dish has a downconverter associated with it. The dish is able to receive the signal of the QO-100 in its original center frequency 10489 MHz, and the downconverter puts all the bandwidth and information of the signal in the 739 MHz frequency.

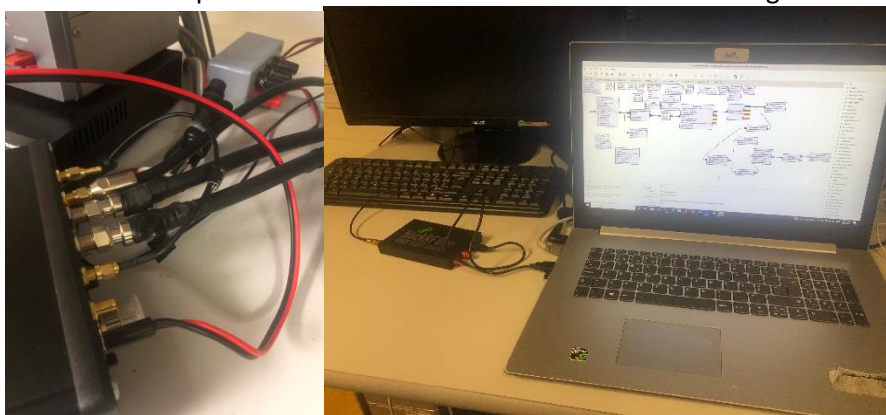


Figure 4.1 - Groundstation

After the downconverter the signal is transmitted to the SDR equipment via a coaxial cable

4.1.2 DXPATROL FULL DUPLEX QO-100 GROUND STATION2.0

This equipment is essentially a receiver that syntonising and downconverters signals from the QO-100 down to the 420.5 MHz, although it can also help in the uplink side of the communication. The QO-100 Ground Station also comes equipped with an enclosed GPS antenna. this comes with the added benefit of stable reception of the signal, as the internal PLL (phase locked loop) is synchronized by the GPS clock.

In the Ground Station the QO-100 can be serve in two ways. The first way is by providing power to the antenna through a generated current, this allows the signal to be better received with more gain. The second is by receiving the signal itself, locking it and then transmitting it in RF. See Appendix B.

4.1.3 SDR equipment

To be able to construct a software defined radio it is necessary to have equipment able to transfigure the signal from the coaxial cable to the CPU that contains the receiver in software.

The equipment chosen for this is the Hack RF One from Great Scott Gadgets. This equipment peripheral capable of transmission or reception of radio signals from 1 MHz to 6 GHz. The hack RF One allows the CPU to receive signals coming through the antenna or coming RF signals from the DX Patrol. This component allows various types of signals to be receive by various types of devices such as raspberry pi, orange, a normal computer, or personal computer exemplifying that way the modularity of SDR and the reducing of cost as an advantage without sacrificing possibilities of combinations in setting up a groundstation. See Appendix C.

4.1.4 The Two Mounting Experiments

The Ground Station as is constructed will allows us to set up two experiments. The first experiment uses the Ground Station in its usual basic configuration. In the second experiment the DX Patrol will be added to the groundstation, this experiment is done to see if the second downconverting of the signal and the syntonising have effects on the information coming through the signal.

5 Setting Up the Multimedia Beacon Receiver

In this chapter, the multimedia beacon receiver will be set up based in a previous work [30], with the objective of improving it. The receiver structure of the main receiver will have two main parts, that of demodulator with a primary role receiving, synchronizing, and restoring signals from the analogue signal to a digital one, and that of a decoder, this part will receive the digital signal and decode it to obtain their information hidden. To be able to operate more smoothly the receiver has a set of variables are in within their own blocks. The justification of blocks is presented in the Appendix A.

5.1 Variables and range

These variables can be set directly on the field of the processing blocks but to set one more than one or for better organization and difficult to express in terms of expressions or large variables it is better to separate them and initialize them in their own set of blocks. These variables can be set in range if an exact value is indeterminant.

Centre Frequency

This variable will simply have the value of the main frequency of the signal. In the first experiment the band of centre frequency will be set to 739 MHz and the second will be in the 432.5 MHz.

Sample rate

This variable will be useful for several processing blocks. The number put on here must follow the Nyquist or sampling theorem meaning that a minimum sampling rate of twice the signal frequency. As this experiment has two modes of operating, one with the QO-100 Dx Patrol with a frequency of 422MHz, and the one with just the downconverter from the antenna has a frequency of 723 Mhz.

Although these values could the limit the value of the variable the Hack RF One has the more limiting effect, as it only works with sampling rates of a least 2 MHz.

Offset_freq

This parameter has no exact value, its range varies. This was done so that the spectrum of the signal could be navigated so that the SSB, multimedia beacon and other transmissions from the QO-100 could be accessed.

Decimation

The parameter of decimation is used for reducing the sampling frequency of a signal to a lower sampling frequency that differs from the original frequency by an integer value. Decimation also is known as down-sampling. The lowpass filtering associated with decimation removes high-frequency content from the signal to accommodate the new sampling frequency. This parameter can be quite important as in the high frequencies this experiment works can affect the hardware in which the receiver works ie computer.

RF gain

This following parameter is not a set value but a range of those. This value represents the gain of the RF signal in the receiver. Be that a high value and a low value in dBs.

SPS

This variable will correspond to the number of samples per symbol present in the receiver system.

Nfilt

In Gnu Radio there are a number of processing blocks that have a parameter that allow the signal to pass through a number of digital filters. This variable represents that number and was given the x number.

Rcc_taps

The complete name of this variable is root raised cosine taps or filters. It is used in signal processing in a receiver to do match filtering, meaning that it can detect pulses from the transmitted signals between all the noise. To design that kind of filter it is used a class within GNU radio named firdes, used to design filter functions. The command is:

```
Firdes.root_raised_cosine(double gain, double sampling_freq, double symbol_rate, double  
alpha, int ntaps )
```

And is instantiated by:

```
firdes.root_raised_cosine(nfilt, nfilt, 1.0/sps, 0.2, int(ceil(15*sps*nfilt)))
```

apsk8

This type of variable is a constellation object. This type of constellation is not one of those set. This object has two parameters: symbol map and constellation points that will be set in variables blocks of their own. In terms of the other field in this object the rotational symmetry is set to 7, dimensionality is 1.

Sym_map

For the configuration of constellation map its symbols must be set. As seen previously the configuration of this type of modulation was set as one outer ring with seven points and one point in the middle of them. The order of points and set value of the variable is [0,4,1,3,2,6,7,5] in order.

Sym_points

The symbol points in APSK modulation are arranged in equally spaced points. And those points are given following this expression [14]:

$$P = r e^{i(\varphi + \frac{2\pi}{n}k)} | k = 0, 1, \dots, n-1$$

Equation 5.1 - 8 APSK Constellation Points

In this expression r represents the radius of ring, φ the angle of desphazemnet and n the number of points per ring. As GNU Radio is a platform that is compatible and uses Python, to be able to configure the equation to gnu radio the following command in Python is used:

```
[0] + list(np.exp(1j*2*np.pi*np.arange(7)/7) * np.sqrt(8/7))
```

Syncword_bits

For the synchronization a 24-bit (8-symbol) syncword is used.

5.2 Demodulator

In setting up a receiver in GNU Radio the first task should be the configuration of the source. In GNU Radio the sources compatible with the Hack RF One or other SDR type equipment is the osmocon sources. In the osmocon sourceblocks the RTL-SDR block is chosen.

5.2.1 RTL-SDR Source

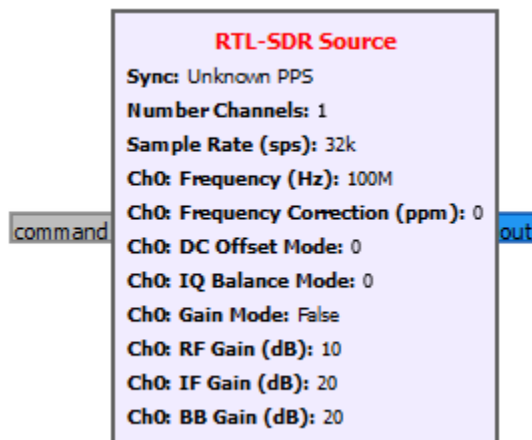


Figure 5.1 - RTL-SDR Block

This block is composed of 17 arguments, but only some are needed to be specified. As the Hack RF one only has the capacity for one channel, we will only be concerned with the channel 0 type

arguments and the number of channels will be put to 1. The channel IQ balance and DC offset can be set to zero as they will not have an impact.

If in the experiment, we are in the need to increase gain the two variables in need of change are the IF Gain and BB Gain because those two can work with Hack RF One while the RF gain doesn't produce much difference with the signal coming through.

The important arguments are the sample rate, set with the variable `samp_rate`, the bandwidth of the channel, and the frequency which represents the central frequency the RF chain is tuned to, in this case the downconverter centre frequency seen in 4.1.1. In the end the signal after this block will have a complex output type conserving all its information from the transmitter to a digital signal.

5.2.2 Frequency Translating Finite Impulse Response Filter

The Frequency Translating Finite Impulse Response Filter (FIR) is a block that performs the job of frequency translation. As it belongs to the FIR type of filters it has an impulse response of finite duration.

The second of the parameters are the taps. The taps can be used to create FIR type of filters, in this case a low pass filter will be created so that the satellite signal can be isolated. That type of filter can be constructed using the `firdes` library of GNU Radio using the following command:

```
firdes.low_pass(1, samp_rate, 3000, 200)
```

where the first parameter relates to the gain, the second the sampling rate, the third the center of transition band and the last parameter the width of transition band in hertz. This field can also contain other elements other than filters such as a variable that controls the RF gain.

The parameter known as centre frequency is essentially the frequency translation offset frequency. If this value is not known, the variable `offset_freq` can be put here to catch that value.

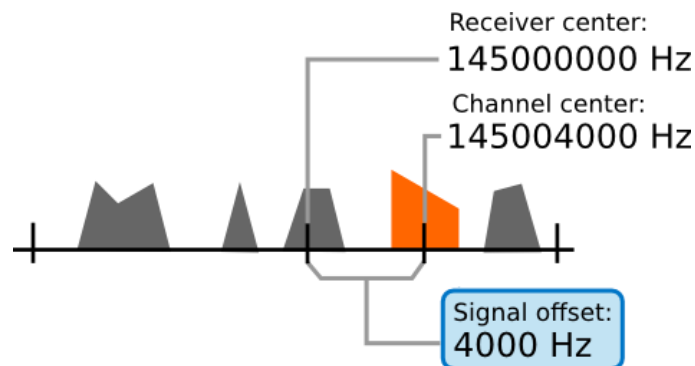


Figure 5.2 - FIR Filter Output

5.2.3 RMS AGC High performance Automatic Gain Control

This block has the sole role of normalizing the power of the signal normalizes so that can be better work on it. This block has a particularity that differentiates from other types of AGC blocks, an RMS component.

5.2.4 Symbol sync

This block has as primary role to perform clock recovery. Its main ability is synchronizing the extracted symbols, making this block one of most importance to a demodulator. To achieve this the block first estimates and tracks the samples per symbol, then it proceeds to perform time synchronization, so that the sampling of the signal is done at the correct moment (the maximum value), finally the samples per symbols is reduced to one reducing or decimating the signal to their individual representations.

The timing error use is the maximum likelihood, with a Polyphase Filter Bank as an interpolating resampler, the output of sampler per symbols is downgrade to one from the input six, and the filter taps are the `rcc_taps`.

5.2.5 Costas Loop

The final component and block used in the demodulator of our receiver is the 8 APSK Costas loop. A generic Costas loop has its main purpose maintaining the synchronization between the local oscillator (receiver) and incoming carrier signal. It locks the centre frequency of a signal and downconverts it to baseband.

For 8APSK modulation only 7 out of 8 constellation points have information about the carrier phase. The point at zero can't be used in the Costas loop. As such for use the Costas loop for the 8APSK constellation a custom block was created. Since the signal coming from the beacon has an excess of bandwidth of 0.2 MHz the sole parameter presents in the block, loop bandwidth will have that value.

5.3 Decoder

The second main constituent part of this receiver is its decoder. A decoder is a device or algorithm that translates encoded or compressed data back into its original format and interpret it. As such our decoder, to be able to recover the original data, has to decode the bits arranged in the modulated constellation, reconstructed the data into frames and do error correction. With that in mind the constitution of decoder is the constituted by the following blocks.

5.3.1 Constellation decoder

This block takes the points from the constellation object and transforms them to unpacked bits. This block receives as a parameter the constellation object that has the constellation of the original signal, then it proceeds to do a comparison between the symbols from the received signal and the constellation object and to determine the transmitted symbol that received point is most likely to represent.

5.3.2 Sync and create packet PDU

In GNU Radio, a PDU is defined as a PMT pair of (metadata, data). The metadata describes the samples found in the data portion of the pair. Specifically, the metadata can contain the length of the data segment and any other information [27]. PDU are important because they give a frame to the information needed to be passed along the receivers. This block has its main role being the message passage between other blocks.

This block has three parameters: Packet length - this number must be the same as the length of the packets sent by the multimedia beacon; Syncword – this parameter will be filled by the previously defined syncword_bits; and syncword threshold-the position of the first bit to be analysed. These three parameters will allow the information of the bits coming from the satellite to be organized and more comfortably analysed.

5.3.3 PDU scrambler

This block is needed to scramble with reed Solomon code words. The only parameter presented in this block is to be filled with a scramble sequence that is defined by an array.

5.3.4 Reed Solomon Decoder

A reed Solomon decoder is part of FEC and optimized for burst errors rather than bits [28].

This block applies the Reed Solomon codes so that corrupted messages can be detected and recover their data from errors.

The parameters of the Reed-Solomon code are taken directly from the Schifra example. The polynomial is the same as the one used in the CCSDS code, but the primitive element and first consecutive root are not: Bits per symbol=8; Generator polynomial =0x187; First Consecutive root=120; Primitive element=1; number of roots=32; and Interleave depth=1.

5.3.5 CRC Check

The CRC Check block receives a PDU containing a CRC at its end and checks whether the CRC is correct. The PDU is sent over the ok or fail output ports according to the result of this check. It can support any CRC whose size is a multiple of 8 bits between 8 and 64 bits.

The block uses the same notation as [this online CRC calculator](#) to define the CRC code parameters. The calculator includes a list of commonly used CRC codes, so it is a useful resource to find the parameters that are needed for this block. The default parameters of CRC Check correspond to the CRC-32 code. The parameters are set to correspond to the output of the Reed-Solomon block.

5.3.6 File Receiver

Finally, we have the file receiver block that will transform that ran all the way across the receiver into a zip and is saved in a specified CPU storage area.

6 SSB Receiver

The final task of this project is the construction of a SSB receiver. Contrasting with the receiver for the multimedia beacon, this one will be simpler as is just used for voice communications. This receiver is more easily used than the receiver for the multimedia beacon, this means that can be used to identify the signal coming from the QO-100 satellite more easily.

As seen in 2.2.5 the SSB signal this type of signal only utilizes the upper side of the communication band. To achieve this in GNU Radio two signal source blocks are added to put the signal in upper side of the band.

The signal itself originates or is received from the RTL-SDR source block with the almost the same parameters as in the multimedia beacon receiver. The first block the signal passe after being received is the DC blocker. The second block, Frequency Xlating FIR Filter is where the signal is filtered its frequency centralized and the noise filtered. With signal already filtered it needs to be normalized for ease of processing, this is done by the block AGC2. Finally, the signal is separated into its real and complex components. These components are multiplied with the two signal source blocks so that the signal the upper part of the signal is received and then they are added.

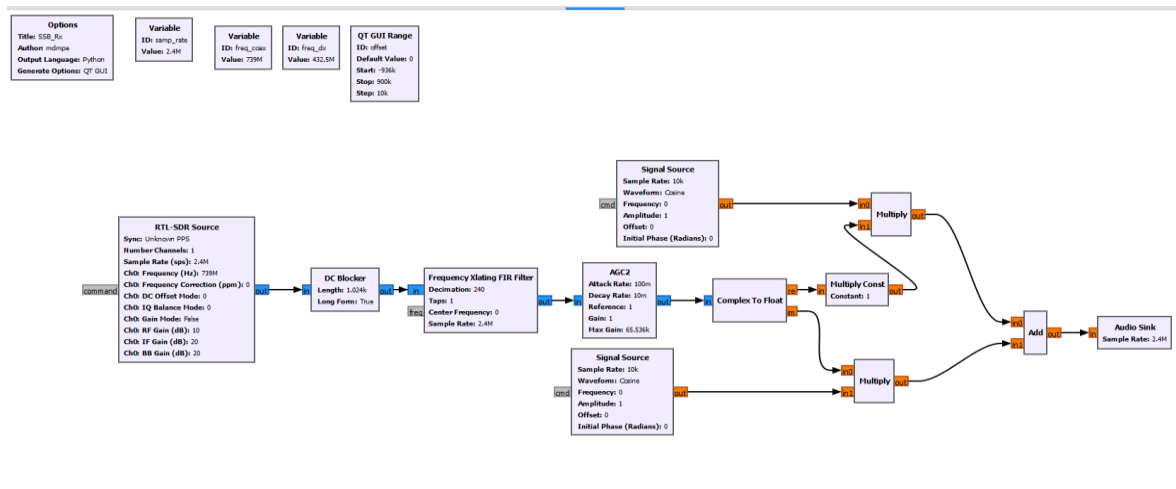


Figure 6.1 - SSB Receiver Fluxogram

7 Auxiliary Blocks

In constructing any kind of receiver in GNU Radio, besides the main blocks designed to receive, demodulate, phase-lock and decode signals there is also need for indications of the signal to noise ratio (SNR), the plot of singles in frequency, time, the constellation diagram, waterfall, and many others. For that reason, the auxiliary blocks were used to better construct the receivers and then analyze the signal coming from them. In the completion of this project there were mainly used three of these kinds of blocks, although sporadically other were used to.

The first of this kind of block is the SNR Estimator probe. As the name suggest this block allow us to know the signal to noise ratio after another block.

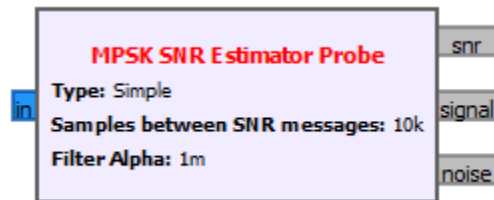


Figure 7.1 - SNR Block

This block receives a complex signal and output the value in dBs for SNR and the signal and noise in separate, those values will be shown in the console. in this project this block was used to check the if the signal was strong after the filters. As the filters used in this project were already designed or of simple designed there was no need to dimension them in applications such as MATLAB, so this block was utilized.

Message Debug is the perfect kind of block to debug the decoding of the signal. The block receives PDUs vectors, in our case sent by the Sync and create packet PDU block, it treats and analyzed them, then it can print them.

Besides PDUS this block can also receive messages and can print them or store them.

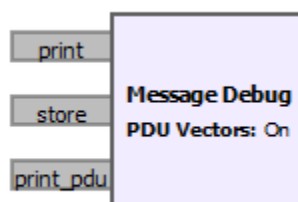


Figure 7.2 - Message Debug Block

Finally, we have the QT GUI blocks, these are a collection of blocks that receive the signal and represent it in a visual way for a better understanding of the signal. These kinds of blocks can be used to help with the construction of the receivers just like the two previous block and can also present information about the signal. They also have a particularity of being used separate or cojoined in a single block but with all the important information. They can contain information of the spectrum, time, constellation diagram, waterfall and other. It will be with these blocks that the next chapter of this project will get the information from.

8 Analysis and discussion of the results

This chapter will contain the results obtained by the two receivers, SSB and Multimedia Beacon in the two types of experiments, with DX Patrol and without. The first task to do after the receivers are designed is to connect the CPU to the Hack RF One USB cable, then we execute the flowgraph of the receivers.

8.1 With LNA

The first results we will look are those where the DX Patrol was not present, meaning that besides antenna and cable, the only component is the Ground Station was a LNA that downconverted the frequency to 739MHz.

8.1.1 Multimedia Beacon

After executing the multimedia beacon receiver, we note that there is no decoding occurring in the console output. Checking with the constellation GUI we do not see the 8 APSK constellation meaning the signal is not being received properly.

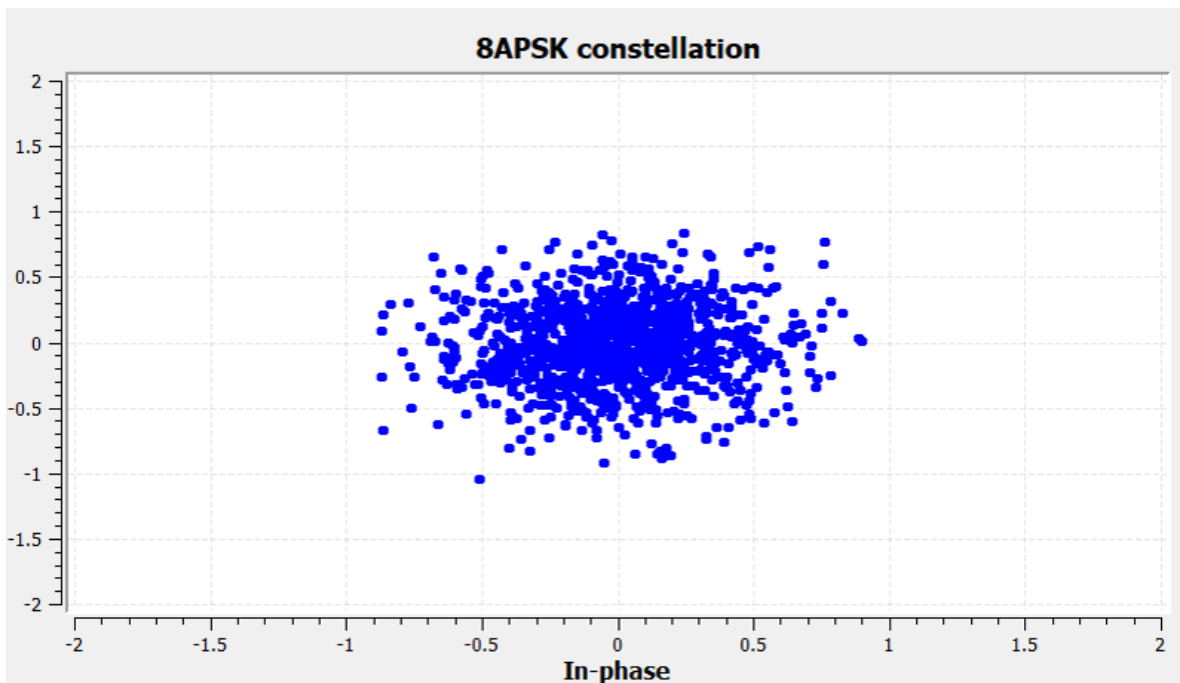


Figure 8.1 - Constellation Map of the signal, 1st experiment.

To confirm the previously seen we check the frequency GUI and see noise and only a spike in the center, but this just seems to be the response of the Hack RF One in the frequency when not receiving a signal.

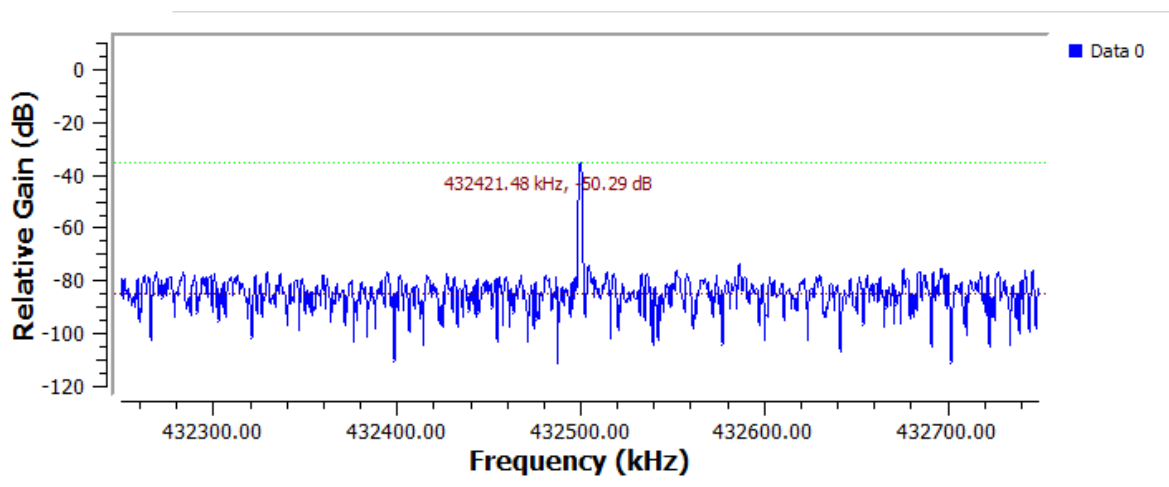


Figure 8.2 - Spectrum of the Signal, 1st experiment.

8.1.2 SSB

Finally, the SSB receiver is activated. In terms of frequency spectrum, we see the same as in the multimedia receiver. The output of the audio sink are sporadic bits of noise, no other sound can be heard, once again confirming that the signals is not being received. As seen in figure 8.2 the maximum in dBs that the response from Hack RF achieves could be close to -50 dBs while the noise is between -90 and -70 dBs.

8.1.3 SNR

To confirm the result that there is no signal being received, the estimator probe is set up on either of the receivers. The output results unexpectedly have a mean value of 20.178, that normally would transcribe to a well-received signal, but in this case the signal being heard seems to be only the response in frequency of the Hack RF One. As the estimator probe has the variable sample between SNR set at 10000, whenever 240 samples are received, a message containing the value of the SNR is sent.

Table 8.1 - SNR of the signal in the 1st experiment [dB]

SNR [dB]	
20.172	19.778
20.530	20.502
19.802	20.132
20.344	18.980
22.401	20.791
18.403	20.302

In this first experiment the signal could not be obtained, but using the DX Patrol we get confirmation that it can receive the signal.



Figure 8.3 - DX Patrol with signal acquired.

As such we move with the second experiment using DX Patrol.

8.2 DX Patrol

In this second experiment we will try to use the DX Patrol to offset the loss of signal as the DX Patrol recognizes that a symbol is being received.

8.2.1 SSB Receiver

The first receiver we execute is the SSB receiver, that way is easier to discover the beacons, because we can hear them. Seconds after the execution a pop up will appear with the chosen QT GUI, in this case the one who represents the signal in frequency. An audio will also appear from the audio sink block. As the audio appears we first need to identify the beacon. Using the variable offset (5.1) the beacon sound is procured, when found we shift the variable in ever smaller offset to found SSB voice communications.

In this first attempt besides the sound of the beacon, no other sound was heard, so the variable controlling the RF gain was increased to 50 dBs. As the beacon was heard this is indeed strange. To discover the root of the problem we create a little displacement between the signal and the center frequency: as we see in image the beacon of Hack RF One has a higher response than the signal itself, that only now appears, the difference between them is 5 dBs.

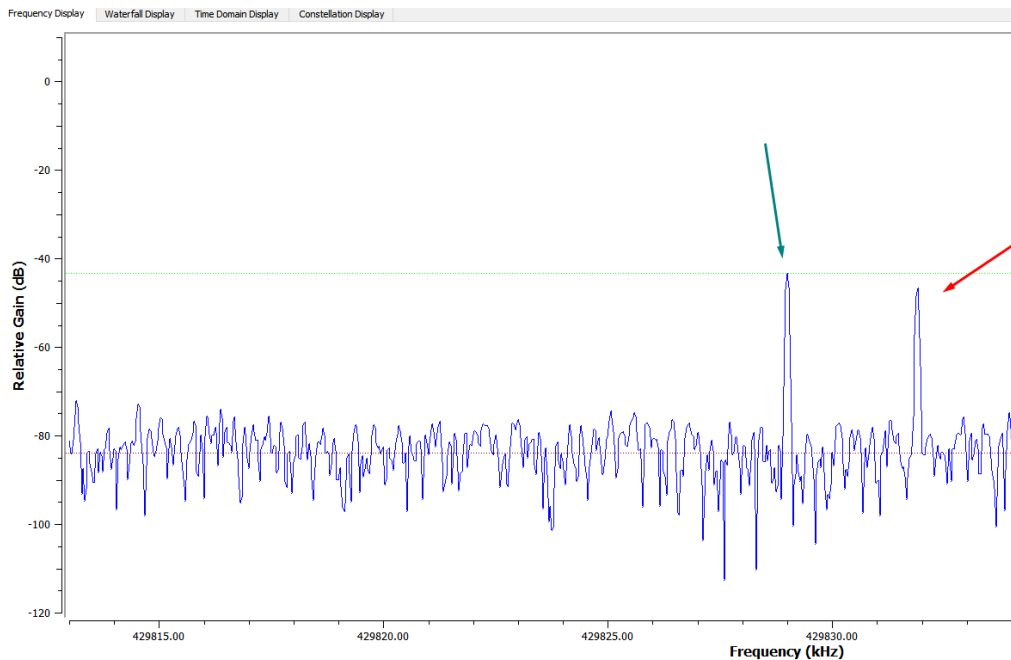


Figure 8.4 - Spectrum of signal (red), signal Hack RF (green), 2nd experiment

To get around this problem a rise in gain must be achieved, this is mostly achieved using the RTL-SDR block, mainly its three gain types: RF gain, IF gain and BB Gain. Of these three the IF and BB gain are equipped to increased gain in a Hack RF. IF Gain represents overall intermediate frequency gain of the device and BB gain overall baseband gain of the device. These two types are in a range of reasonable gains between 15 and 30 dBs. To be able to match these three types of gain range variables are used. First, we enter the SSB frequency already determined to hear the beacon, then using the sliders we adjust the gain to be able to hear the voices from the SSB beacon. This time around voices communications have been heard, this comes with the caveat that the values of the gain utilized surpass the recommend maximum 30 dBs, and that way the voices still come with some noise as seen in the figure 8.4. The values of gain will be then 55 dBs for IF gain and 50 for BB gain.

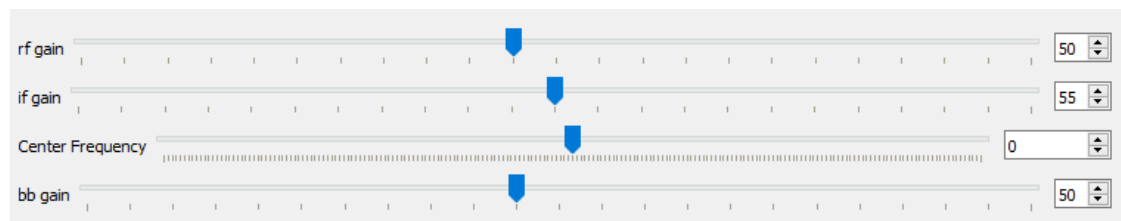


Figure 8.5 - Setting the increase in gain

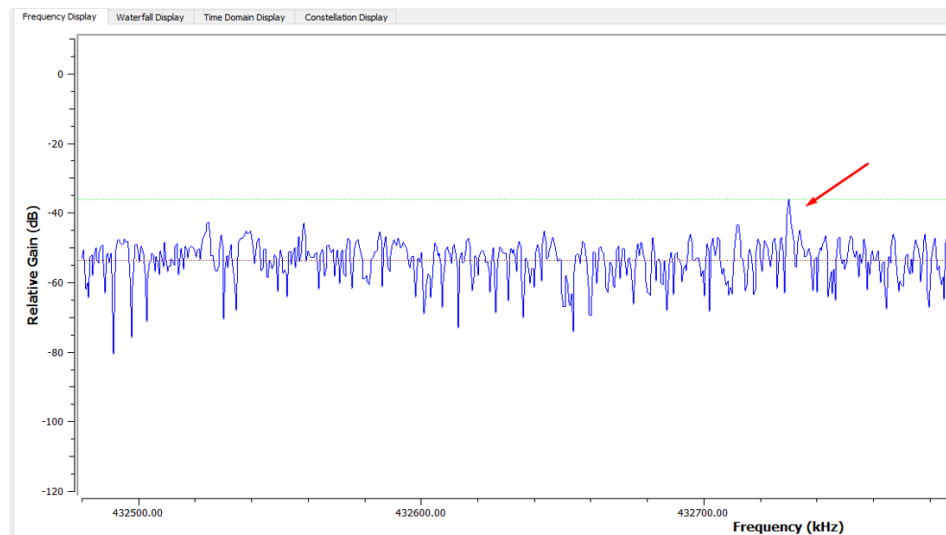


Figure 8.6 - Spectrum of the signal with increase gain, 2nd experiment.

By analyzing the output of this receiver figure 8.7 the console output gives the message 'OOO', this message means or represents an overflow, meaning the CPU cannot keep up with the incoming data. A possible resolution to this problem is to downgrade the sampling rate, but as the sampling rate has a minimum possible value to work with Hack RF One of 2 MHz, this is impossible. This means that is impossible to have a better voice resolution that the one present for SSB signal being received.

```
pagesize :error: no info; setting pagesize = 4096
OOO
>>> Done
```

Figure 8.7 - Console output SSB receiver

8.2.2 Multimedia beacon receiver

As the SSB receiver heard the beacon in the 432.73 MHz of frequency, we can set the offset value from the SSB receiver to this receiver, to decode the beacon. The first time we use this receiver is with the reasonable values set in 5.2 for the gains. When the receiver is run the frequency GUI shows the same results as obtained with the SSB receiver, but the constellation GUI shows a strange constellation.

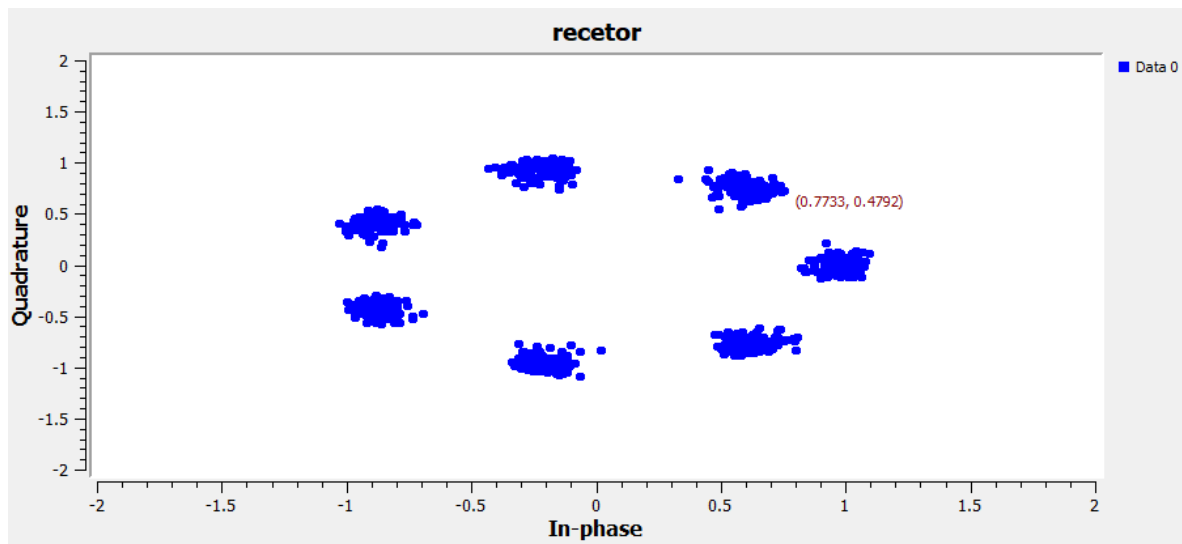


Figure 8.8 - Constellation Map of the signal, 2st experiment

This constellation is strange because is not like any known modulation constellation, it has seven points in a concentric ring, missing the center point representing zero. In terms of console output the receivers transmits the following message.

```
FileReceiver: new file 0
decode_rs :debug: Reed-Solomon decode fail (interleaver path 0)
FileReceiver: received sequence 576 for file 0
```

Figure 8.9 - Console output multimedia beacon

This message says that a file was received from the signal, but there is also one decoding fail. The file received has the following aspect.

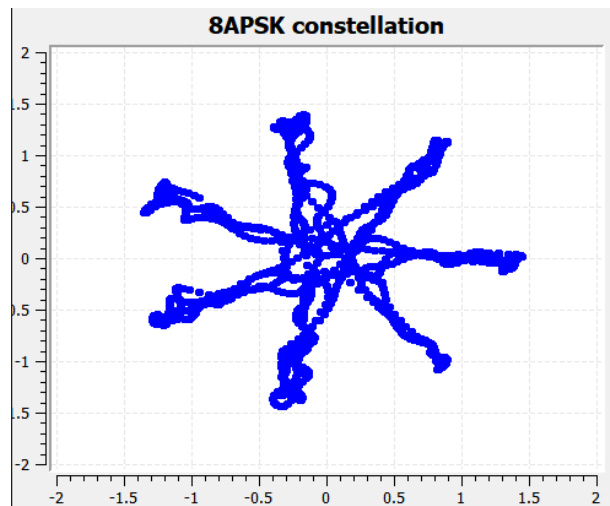


Figure 8.11 - Constellation Map of the signal with increased gain, 2st experiment

The console shows us that the decoding still didn't work and on top of that the overflow message also appeared. So, the computer could not increase the gain or sampling rate more. So with increased gain the file still has missing information probably cause by lack of symbol zero.

```
OOcorrelate_access_code_tag_bb :debug: writing tag at sample 1191011
FileReceiver: new file 0
decode_rs :debug: Reed-Solomon decode fail (interleaver path 0)
FileReceiver: received sequence 576 for file 0
```

Figure 8.12 - Console output multimedia beacon with increased gain

8.2.3 SNR

To compare it with the experiment using DX Patrol with the one without it we need to compare the SNR. So again, the SNR estimator probe is set on either receiver, as they get the same signal. As the QO-100 signal is now visible and heard we do not expect the same results as in the other experiment as the response from the Hack RF One is now mitigated.

Table 8.2 - SNR 2nd experiment [dB]

SNR [dB]	
16.795	15.668
16.147	15.300
14.985	14.364
14.737	14.214
14.537	14.082

As seen in the table the relation is now smaller, median of 12.569, suggesting that now the signal is being observed.

8.3 Solving the missing symbol

With the decoding problem in mind, we need to find the cause and treat it. As we can see the decoding fail is both present with or without increased gain, and we can infer that is caused by the missing constellation point at zero. The problem of the missing symbol can be caused by one or two causes:

1-Problem with the 8 APSK Costas Loop. As seen in chapter 5.2.4, the Costas Loop is the component that phases lock the signal. This block is also created with the satellite branch in mind, and maybe cannot properly deal with the 8APSK modulation as its rarer and not generalized.

2-Problem receiving the signal. The missing zero symbol could be caused by lack of power of the signal.

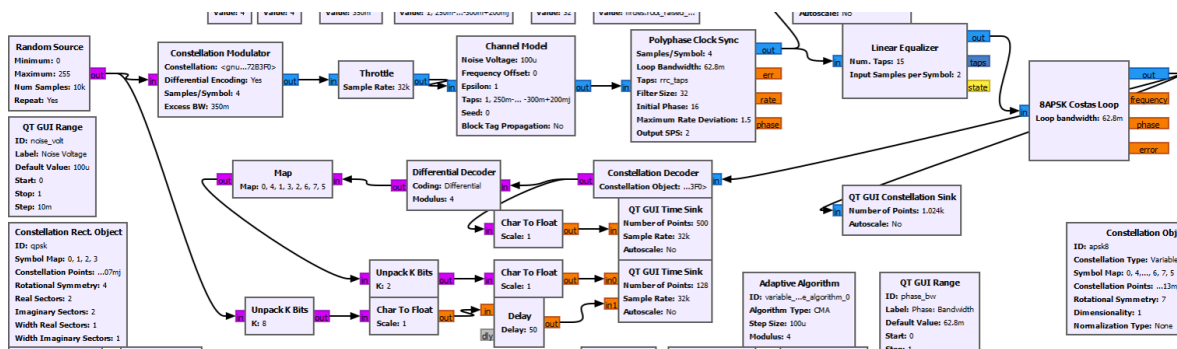
8.3.1 Costas Loop Resolution

The problem with the Costas Loop could originate from two things:

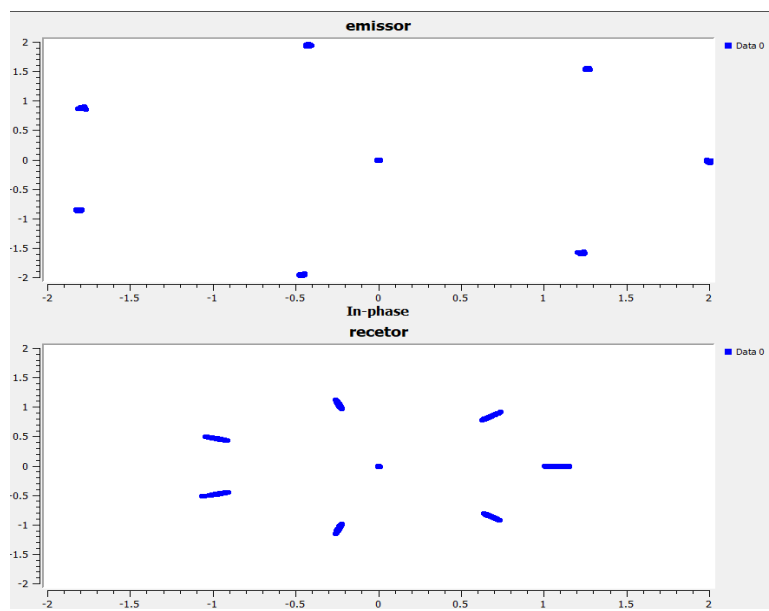
- 1.1-The constellation design was wrong, and the points do not match in symbol sync.
- 1.2-The generalized Costas Loop doesn't work. A new Costas Loop must be created.
- 1.3 Gnu Radio is not compatible with 8 or another APSK modulation.

1.1 Constellation Design

To check if the constellation object is set up correctly, a mock transmitter needs to be constructed. This mock transmitter will take a random source signal block and then modulate the signal with the constellation object 8 APSK to be then decode by the receiver.



When the transceiver is running the outputs demodulates nicely the signal.



This would suggest that the constellation object and the demodulator were constructed correctly.

1.2 Costas Loop

Thanks to the modularity and customizable nature of GNU Radio, using python we can construct our own Costas Loop using some examples [29].



So, in python our own 8 APSK Costas Loop is created.

```

def work(self, input_items, output_items):
    for j, x in enumerate(input_items[0]):
        output_items[0][j] = z = x * np.exp(-1j * self.phase)
        if np.abs(z) <= 0.5:
            error = 0
        else:
            error = (np.angle(z) * 7 + np.pi) % (2*np.pi) - np.pi
            self.freq += self.beta * error
            self.freq = np.clip(self.freq, -self.freq_limit,
self.freq_limit)
            self.phase += self.alpha * error + self.freq
            self.phase = (self.phase + np.pi) % (2*np.pi) - np.pi
    return len(output_items[0])

```

the line of code in specific that tentatively can resolve the problem is:

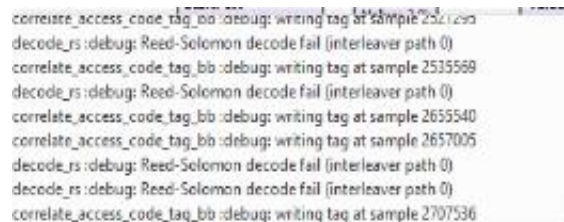
```

if np.abs(z) <= 0.5:
    error = 0

```

meaning that if the absolute value of amplitude of the signal is on what can be considered to be point zero (0.5 or less), the error at that place can be ignored.

Using this customized Costas Loop, the output of the console shows the same as with the generalized 8APSK Costas Loop.



```

correlate_access_code_tag_bb: debug: writing tag at sample 2535290
decode_rs: debug: Reed-Solomon decode fail (interleaver path 0)
correlate_access_code_tag_bb: debug: writing tag at sample 2535569
decode_rs: debug: Reed-Solomon decode fail (interleaver path 0)
correlate_access_code_tag_bb: debug: writing tag at sample 2655540
decode_rs: debug: Reed-Solomon decode fail (interleaver path 0)
correlate_access_code_tag_bb: debug: writing tag at sample 2657005
decode_rs: debug: Reed-Solomon decode fail (interleaver path 0)
correlate_access_code_tag_bb: debug: writing tag at sample 2707536

```

Figure 8.16 - New Costas Loop console output

1.3 APSK Modulation in SDR

To check if the problem stems from GNU Radio, another SDR application GQRX will run receiving the signal from DX Patrol.

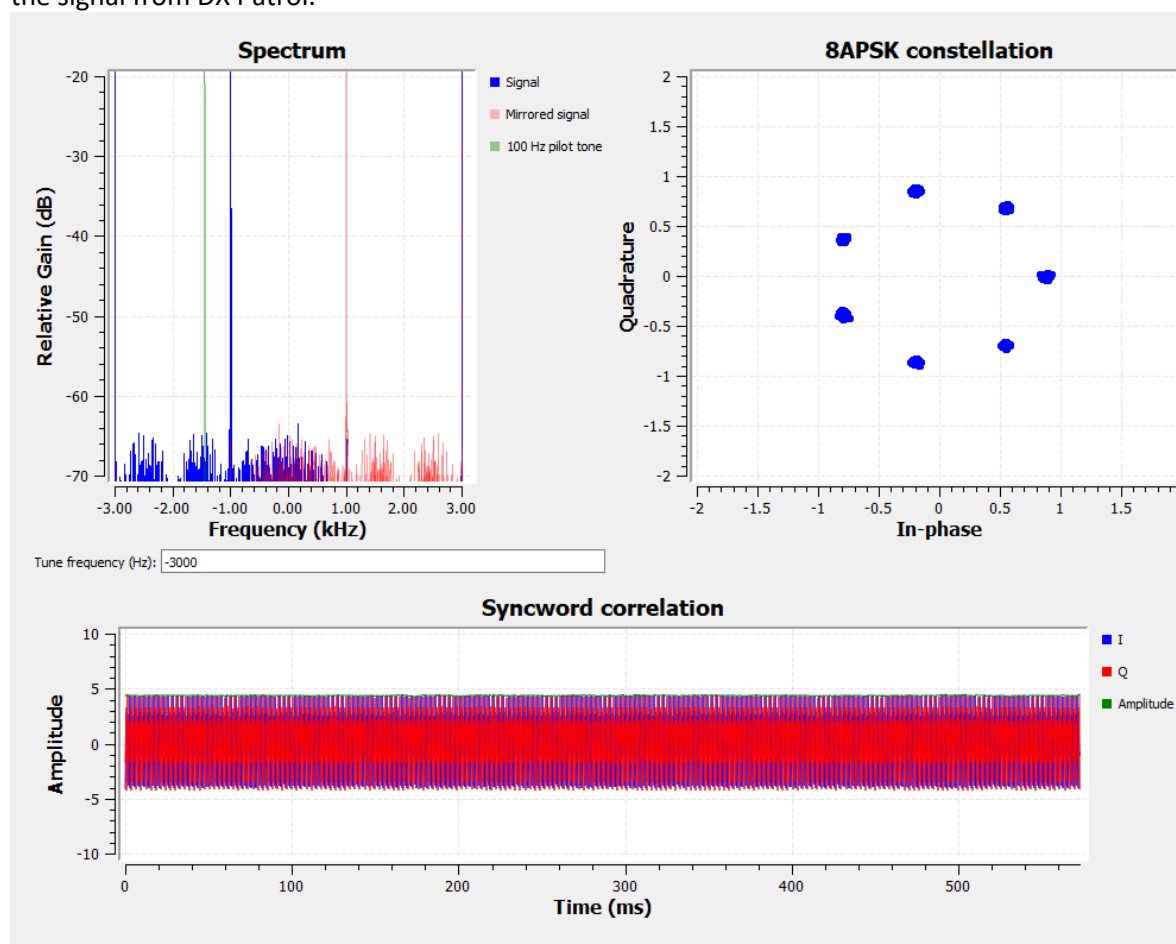


Figure 8.17 - GQRX receiving the QO-100 signal

8.3.2 SDR Hardware

As seen in the 8.17 figure, the application corroborates the findings of GNU Radio. As the problem wasn't with the Costas Loop, we tried to check if the signal itself is being received. With that it minds we must check three things:

2.1-Problem with drives. Although the no error message in terms of compatibility was shown some hidden error may appear.

2.2- Problem with Hack RF One or GNU Radio. AS GNU Radio was firstly designed to Linux some compatibility issue could be at fault, or Hack RF One could be damaged.

2.3- Problem on the power that the signal received itself. Lastly the final hypothesis is if the signal is not present or as low power.

2.1 Drive Problems

To install correctly the drive to SDR equipment the application Zadig is used.

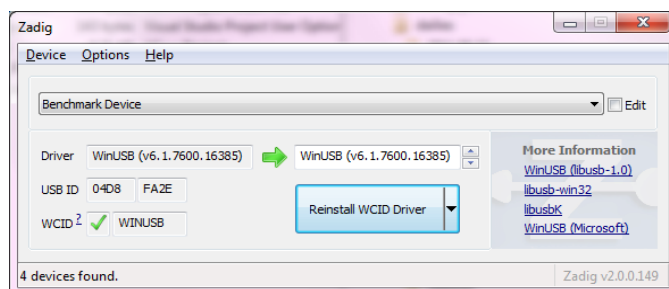


Figure 8.18- Driver installation in Zadig

This application is easy to use. We only have to select the device and install the drivers. Unfortunately, after installing and reinstalling drivers both receivers had the same behaviour.

2.2 Hack RF One and GNU Radio

To check if GNU Radio was having compatibility issues a virtual machine was setup with GNU Radio and the designed receivers.

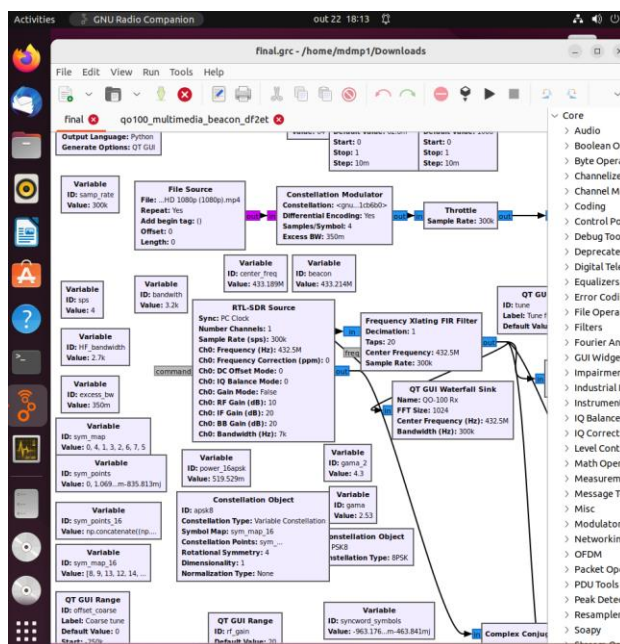


Figure 8.19 - QO-100 receiver in Linux

The results similar but the sampling rate had to be downgraded since the overflow messages had appeared.

9 Conclusion

In this final chapter we will present the conclusion of this project using aspect from the previous chapters. Those aspects will be interpreted using the results from the previous chapter. A limitation of the study and proposal for further work will also be stated.

9.1 Main conclusions

The main objective or aim of this project was to build using SDR techniques receivers that could decode satellite beacons, in particular the SSB and multimedia beacon of the QO-100 Satellite. To complete that task two receivers were constructed in GNU Radio, those receivers are connected through a CPU to a Hack RF One which in turn is connected to the groundstation.

To make sure the software receiver was well structured, it was analysed the structure of modern digital and analogue receiver. The type of signal coming from the satellite was also analyzed and also the frequency band it belongs to, as the satellite is a geostationary one the effect its signal suffers as it enters the atmosphere is studied because of the high frequency coming from the satellite.

After analyzing all that information and in consequence with that a Ground Station was constructed. It comprised an antenna, LNA, coaxial cable, Hack RF One and a CPU. In one experiment the Ground Station also comprised of the DX Patrol and another without it.

Through analysis of the results, it appears that the experiment without the DX Patrol failed to provide meaningful results. The multimedia receiver didn't receive any file and the SSB receiver failed to capture any sound apart from noise. The signal received didn't appear and only the response in frequency of the Hack RF One was visible. In the experiment that used DX Patrol results were achieved. The SSB receiver at first only produced noise, but with a large increase in gain it was able to receive SSB communication occurring around the globe passing through the QO-100. The multimedia receiver was also able to receive a file, that file was missing information, this is due to a decoding error in the receiver, the symbol representing zero was missing. An increase of gain also was unable to solve it. As seen in the previous chapter the problem seems to be the lack of power of the signal. That lack of power can't be from the signal coming from space since it was stated in this project that that had no consequential effect, the lack of power then must belong to the coaxial cable. The signal when received had a SNR of about 12.5 with highs of power reaching the -20 dBs while minimums could achieve -80 dBs.

9.2 Limitations

While this project was able to achieve results it also had major limitations.

The greatest limitation was caused by the loss of the signal coming through the coaxial cable, which impeded one experiment and heavily. To a SDR equipment such as Hack RF One the loss of power can also be quite detrimental.

Another limitation was the limits of the CPU in trying to offset the loss of power with increase gain which often led to overflow.

9.3 Future Work

This type of project has a lot of derivatives and follow up work.

- SSB transmitter. As the SSB receiver can received voice communications the logical step to make would also be to have a transmitter.
- DATV receiver. The QO-100 as also more transceiver such as for DATV.
- WEB SDR. The signal and beacons coming from the satellite could be made to be available outside of the groundstation.
- Satellite telephone.
- Other project from SDR, radio-amateurs and GNU Radio, amateur astronomers such the *'Signal from Space'*.

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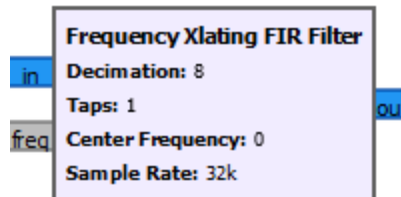
APPENDICES

APPENDIX A

This appendix will contain information pertaining to the construction of the multimedia beacon receivers' blocks.

Frequency Translating Finite Impulse Response Filter

This block has five field or parameters: type, decimation, taps, center frequency and sample rate. The type represents the type of signal is introduced, the type of signal produced after taps and what type of taps and we chose, in this case is complex to complex using complex taps. That will have an effect that the filter would not have to be symmetric in frequency.



RMS AGC High performance Automatic Gain Control

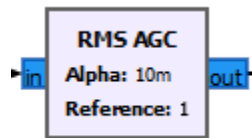
RMS is root-mean-square value of a signal and is calculated using the following expressions:

$$p_{n+1} = (1 - a)p_n + a|x_n|^2$$

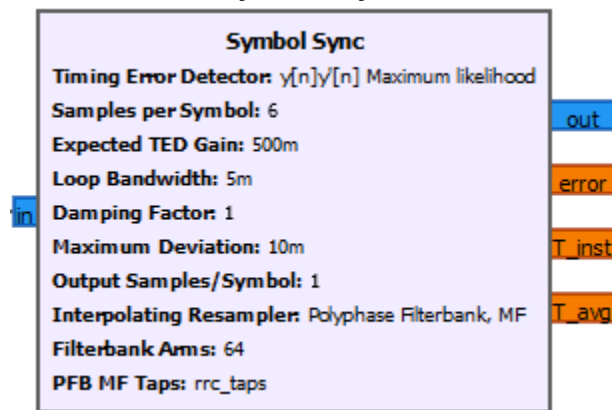
$$r_n = \sqrt{p_n}$$

The parameter a presented on the formula has a good work value of 0.01 the other parameter presented in this block, is the reference value, and in each step transforms the input into output as well as updating the gain.

$$g_{n+1} = g_n + a(R - |y_n|)$$



Symbol sync



This block has eleven parameters.

Timing Error Detector

Timing Error Detector (TED) this parameter allows for seven types to be chosen with correspondingly different types of clock recoveries.

Gardner TED

Gardner TED is continuously adjusting the timing of the local clock based on the timing error estimate, even in the presence of phase and timing variations caused by channel noise and other factors, that is achieved by different calculation of early and late sampling (which can be taxing on hardware

Zero crossing

Another of the options provided is zero crossing, this method uses the namesake zero crossing detection, the sampled signal is examined to detect when it crosses zero, this is done by negating the slope.

A zero crossing is a point where the signal changes polarity from positive to negative or vice versa. These zero crossings represent points in time when the signal is transitioning between symbols. simple yet effective technique for symbol timing recovery. It's particularly useful in scenarios where the received signal has well-defined zero crossings, such as in phase-shift keying (PSK) and amplitude-shift keying (ASK) modulation schemes. However, it may not be as effective in situations with high noise levels or complex signal waveforms such as in this project.

Muller and Muller

An option that has a standard and modified options. In this mode Mueller and Muller algorithm is the cross product in its expression: matched filter output at a symbol time is multiplied with the previous symbol value, one filter is aligned with the early samples, and the other is aligned with the late samples. The early filter responds to samples taken before the expected sampling instant, while the late filter responds to samples taken after the expected instant.

Filtering and Combining: The output of the early filter is subtracted from the output of the late filter. The resulting signal represents the timing error or phase difference between the early and late samples. It's commonly used in receiver designs for various modulation schemes, including quadrature amplitude modulation (QAM) and phase-shift keying (PSK).

Early Late

The early samples are taken slightly before the expected sampling point (early samples), and the late samples are taken slightly after the expected sampling point (late samples). We saw that the timing matched filter is constructed by computing the derivative of the matched filter and consequently its output is the derivative of the input signal. Naturally, this output is more fine-grained and hence accurate when the number of samples/symbols is relatively low, something that does not correspond to this iteration of the project.

L

L, is used in most applications for reducing the complexity of the timing locked loop, which is far more desirable than achieving the gains from the increased granularity.

D'Andrea AND Mengali

The received GMSK-modulated signal is sampled at a rate determined by a local clock or oscillator. These samples are taken at the expected symbol timing instants. GMSK signals exhibit smooth phase transitions between symbols.

The TED typically employs a derivative filter to emphasize the phase transitions in the received signal. The filtered signal is multiplied by a locally generated reference signal, which is typically a frequency-modulated signal that matches the expected phase transitions of the GMSK signal. The D'Andrea and Mengali GMSK TED is tailored to the characteristics of GMSK modulation as such is not convenient to this project.

Maximum likelihood

One of those types is the use of maximum likelihood criterion, this method has a 3 step process, frequency recovery, obtaining an expression of the timing estimate and then finally a phase estimation.

This is the type chosen because it is reliable and not hard on the hardware. In this instance to prevent problems with the constellation point at zero $y[n]y'[n]$ is used instead of $\text{sign}(y[n]y'[n])$.

Samples per symbol

This parameter will be filled with the variable `sps`.

Expected ted gain

This value is the slope of timing error detector without timing offset. The objective of this parameter is to compute the loop bandwidth desired and damping factor.

Loop Bandwidth

This parameter represents the value of the loop bandwidth of the symbol lock tracking loop. This variable is usually discovered by widgets in a trial-and-error method.

Damping factor

In summary, the damping factor is a crucial parameter that characterizes the behaviour of systems undergoing oscillations or transient responses. It provides insights into how quickly the system returns to its equilibrium state or stabilizes after being disturbed. This value will be set at 1.0 becoming a critically damped loop meaning that the system will return to a equilibrium state as fast as possible.

Max deviation

A parameter that represents the value of a maximum deviation of average clock period, its value is represent in units of samples per symbols.

Output samples per symbols

This value will equate the symbols of the output digital signal to the samples. Meaning the value will be set to 1 for ease of the treatment of the signal.

Interpolating Resampler Type

This parameter allows us to choose a type of interpolating resampler. Interpolation resamplers allow us to change the sample rate of a digital signal while maintaining its content allowing us to generate between the original samples of the signal generate new samples.

The Polyphase Filter Bank is a technique that besides producing a flat response, supresses the out of band signals.

This technique can be chosen with minimum mean square error, or a MF to define an error signal or a MMSE with an 8 tap fir filter.

With these choices in mind, the Polyphase Filter Bank with a MF filter will be chosen.

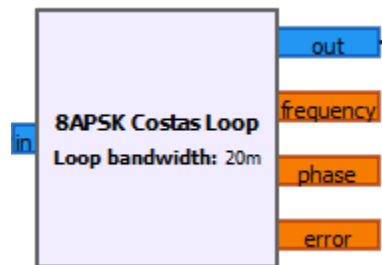
Num filters

This parameter can only be filled if certain Interpolating Resampler Type are chosen as it's our case PFB. Through simulation it was chosen 24.

PFB taps

Because of our choice in the int Interpolating Resampler Type parameter this value has to be filled with the variable rcc_taps.

Costas Loop



More particularly the way the Costas loop works is as follows: the signal arrives in the Costas Loop and is divided into the Q and I constituents, these are passed into a low pass filter and rejoined, together they will pass through the loop filter and then through the VCO, then as many times as necessary the same path will be repeated.

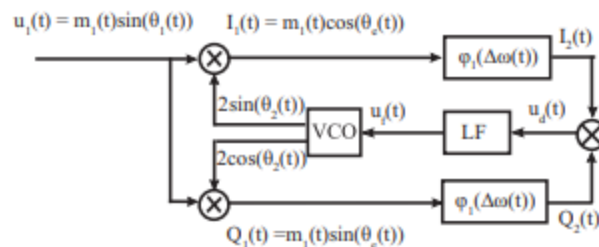
When order=2: used for BPSK where the real part of the output signal is the baseband BPSK signal, and the imaginary part is the error signal.

When order=4: can be used for QPSK where both I and Q (real and imaginary) are outputted.

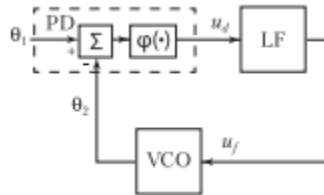
When order=8: used for 8PSK.

In terms of function is similar to a QPSK which in turn is similar to a BPSK Costas loop, as such the loop filter transfer equation for these and for 8APSK can be described as:

$$H_{LF}(S) = \frac{U_f(S)}{U_d(S)} = \frac{1 + s\tau_2}{s\tau_1}$$



Where U_f is the output of the loop filter and U_d the input. The output of is used to adjust the VCO frequency.



Reed Solomon Decoder

The code is arithmetic speaking generated from a primitive element that can be described as the following generator polynomial expression:

$$g(x) = (x - a)(x - a^2)(x - a^3) \dots (x - a^{2t})$$

At the receiver end we perform the following methods:

The receiver receives $r(x)$ at the receiver end.

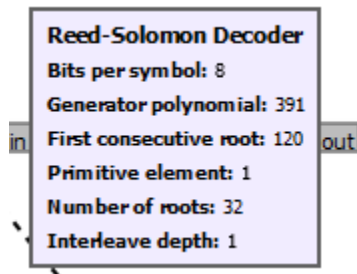
If $s(x) = r(x)$ then $r(x)/g(x)$ has no remainder.

If it has remainder, then $r(x) = p(x) * g(x) + e(x)$ where $e(x)$ is an error polynomial.

The parameters of this code is as follows: block length(n) is given by:

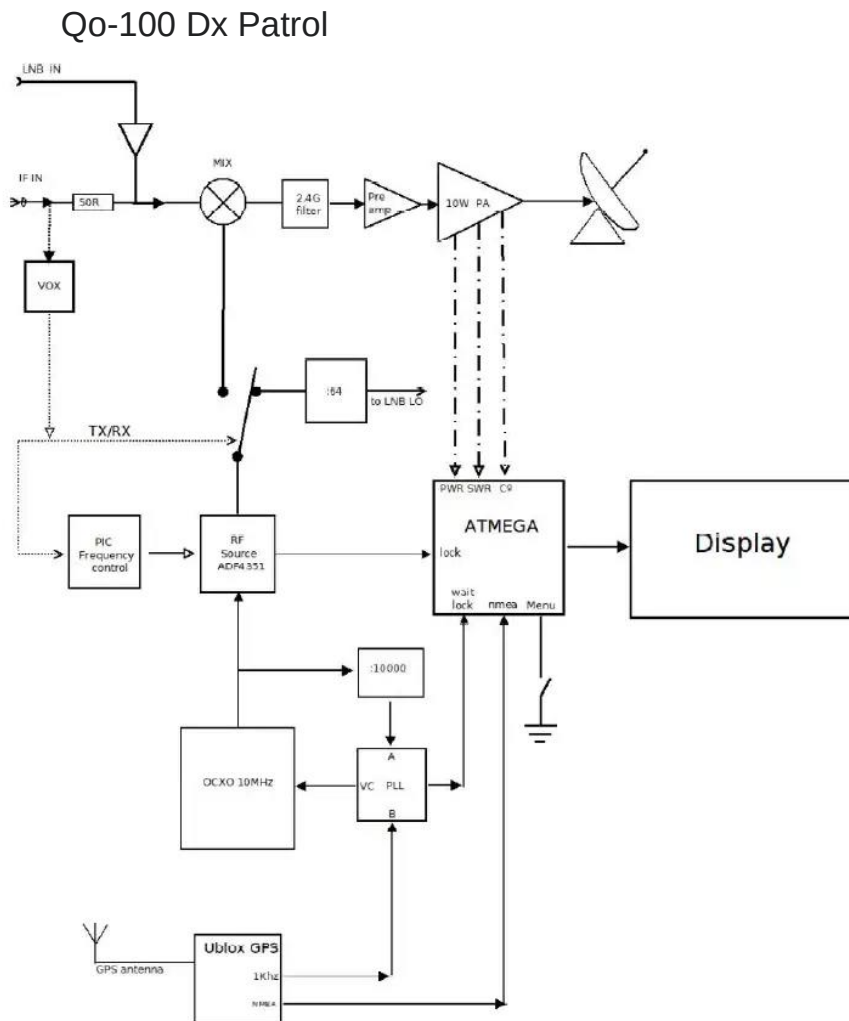
$$2^m - 1,$$

the message size is $(n - 2t)$, these parameters are transformed in the block.



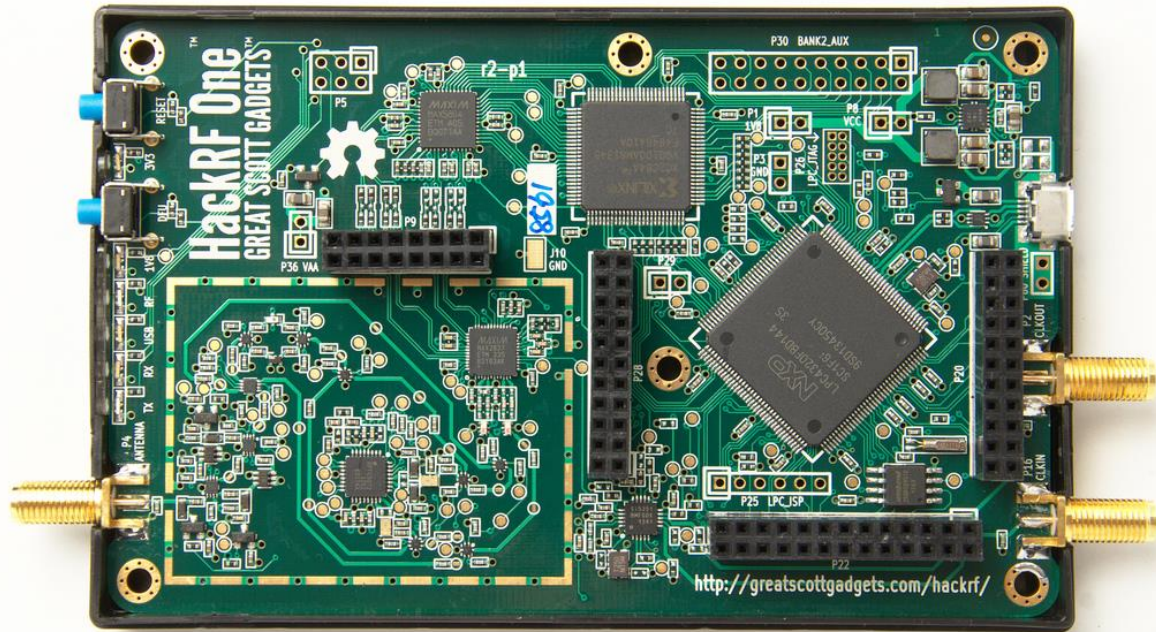
APPENDIX B

This appendix will show the circuit of DX Patrol.



APPENDIX C

Hack RF One



Features

- half-duplex transceiver
- operating freq: 1 MHz to 6 GHz
- supported sample rates: 2 Msps to 20 Msps (quadrature)
- resolution: 8 bits
- interface: High Speed USB (with USB Micro-B connector)
- power supply: USB bus power
- software-controlled antenna port power (max 50 mA at 3.0 to 3.3 V)
- SMA female antenna connector (50 ohms)
- SMA female clock input and output for synchronization
- convenient buttons for programming
- pin headers for expansion
- portable

Hardware Components¶

- Major parts used in Hack RF One:
- MAX2837 2.3 to 2.7 GHz transceiver
- MAX2839 2.3 to 2.7 GHz transceiver
- substitution for MAX2837.
- MAX5864 ADC/DAC
- Si5351 clock generator
- AN619: Manually Generating an Si5351 Register Map
- Other Documentation - includes application notes, user guides, and white papers.
- CoolRunner-II CPLD
- LPC43xx ARM Cortex-M4 microcontroller
- User Manual
- Other Documentation (LPC4330FBD144) - includes errata and application notes.
- ARM-standard JTAG/SWD connector pinout
- BSDL file for the LPC43xx (For boundary scan)
- RFFC5072 mixer/synthesizer
- Datasheet
- Other Documentation: click “Technical Documents” - includes programming guides and application notes.
- W25Q80BV 8M-bit Flash

LEDs¶

When Hack RF One is plugged in to a USB host, four LEDs should turn on: 3V3, 1V8, RF, and USB. The 3V3 LED indicates that the primary internal power supply is working properly. The 1V8 and RF LEDs indicate that firmware is running and has switched on additional internal power supplies. The USB LED indicates that the Hack RF One is communicating with the host over USB.

The RX and TX LEDs indicate that a receive or transmit operation is currently in progress.

Buttons¶

The RESET button resets the microcontroller. This is a reboot that should result in a USB re-enumeration.

The DFU button invokes a USB DFU bootloader located in the microcontroller's ROM. This bootloader makes it possible to unbrick a Hack RF One with damaged firmware because the ROM cannot be overwritten.

The DFU button only invokes the bootloader during reset. This means that it can be used for other functions by custom firmware.

To invoke DFU mode: Press and hold the DFU button. While holding the DFU button, reset the Hack RF One either by pressing and releasing the RESET button or by powering on the Hack RF One. Release the DFU button.

External Clock Interface (CLKIN and CLKOUT) ¶

Hack RF One produces a 10 MHz clock signal on CLKOUT. The signal is a 3.3 V, 10 MHz square wave intended for a high impedance load.

The CLKIN port on Hack RF One is a high impedance input that expects 3.3 V square wave at 10 MHz. Do not exceed 3.3 V or drop below 0 V on this input. Do not connect a clock signal at a frequency other than 10 MHz (unless you modify the firmware to support this). You may directly connect the CLKOUT port of one Hack RF One to the CLKIN port of another Hack RF One.

Hack RF One uses CLKIN instead of the internal crystal when a clock signal is detected on CLKIN. The switch to or from CLKIN only happens when a transmit or receive operation begins.

To verify that a signal has been detected on CLKIN, use `hackrf_clock -i`. The expected output with a clock detected is `CLKIN status: clock signal detected`. The expected output with no clock detected is `CLKIN status: no clock signal detected`.

USB Cables¶

The USB cable you choose can make a big difference in what you see when using your Hack RF and especially when using it around between 120 and 480 MHz where USB is doing all its work.

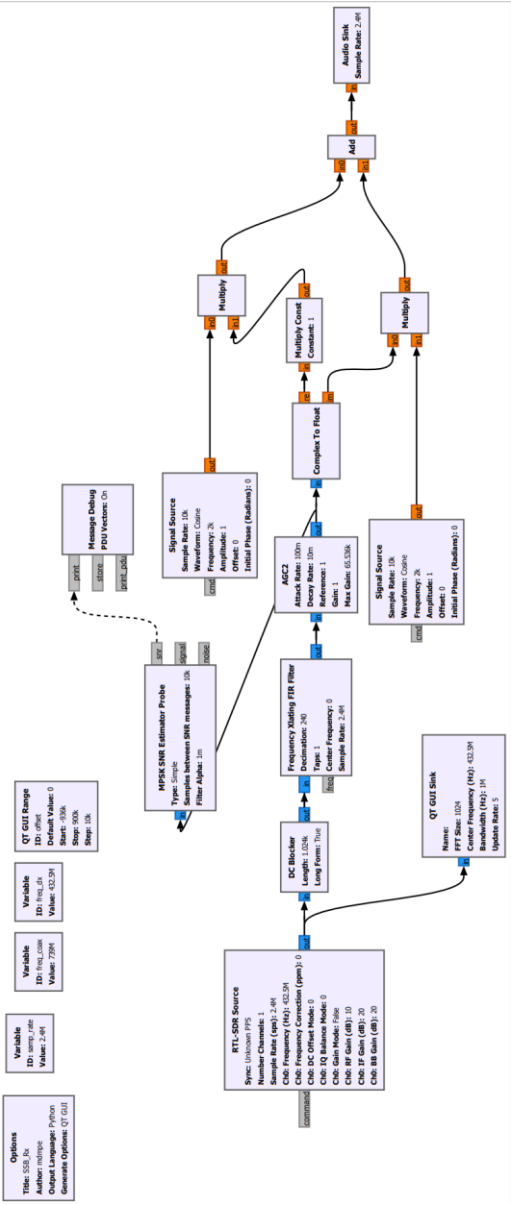
Use a shielded USB cable. The best way to guarantee RF interference from USB is to use an unshielded cable. You can test that your cable is shielded by using a continuity tester to verify that the shield on one connector has continuity to the shield on the connector at the other end of the cable.

Use a short USB cable. Trying anything larger than a 6ft cable may yield poor results. The longer the cable, the more loss you can expect and when making this post a 15ft cable was tried and the result was the Hack RF would only power up halfway.

For best results, select a cable with a ferrite core. These cables are usually advertised to be noise reducing and are recognizable from the plastic block towards one end.

APPENDIX D

Multimedia Beacon Receiver Fluxogram



SDR Techniques to Decode Satellite Beacons

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Abstract—As the technology of satellite communications advances and the need to teach and learn about satellite communications also grew. This paper will present a way of receiving a satellite signal for the QO-100, a geostationary amateur satellite. The signal could come from the QO-100 multimedia beacon or the SSB beacon. A receiver will be constructed using SDR techniques in GNU Radio to demodulate and decode the beacons.

KEYWORDS: SDR, GNU Radio, QO-100, SSB, Multimedia beacon

I. INTRODUCTION

As technology progresses the need for a more interconnected world is greater. To be able to accommodate this trend telecommunications infrastructure has in the coming years been improved and expanded, satellite communication is an integral part of that project.

A. Satellite Communications

Satellite communications has a major gripe on communication all around the world. It allows for communication even in the most remote of areas, the services it provides range from television and military services to amateur radio communications [1]. Telecommunication satellites can be divided into three groups that represent their orbits, these orbits can also, but not always be deterministic in their operations or objectives. Low Earth orbit corresponds to a circular orbit from 160 to 200 kms above earth's surface, and have a period of about 90 minutes, this means that they change their relative position to earth quickly. To cover the entire earth at least 20 LEO satellites are needed. Medium Earth orbit from goes from 2000km to 35700 km, and its satellite are very much similar to LEO satellites in terms of functionality, although visible for a time and have higher footprint that comes to a disadvantage is the longer time delay given the altitude of the satellites. Geostationary orbit positioned above 35700 km earth surface and complete an orbit with a period of 24h. This means that the satellite will appear motionless to an observer on earth, in this orbit there is no need for tracking antennas since the satellites are fixed in a position on the sky.

B. Software Defined Radio

Software Defined Radio as the name suggests is a collection of hardware and software technologies that can substitute

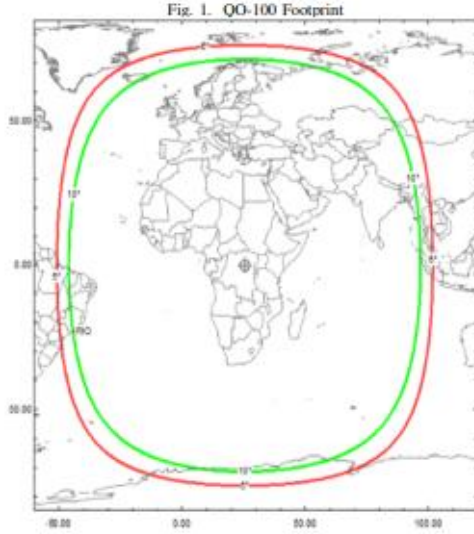
an analogue or digital. A SDR system is usually composed of a radio front end (antenna, cables and other similar equipment's) and a digital back end (this is where the digital components of a receiver can be added or constructed). This type of technology has large benefits to it such as a large reducing of cost, driven by the substitution of large part of the physical components. With the physical components being substituted by software, this allows a more rapid implementation and new features added while the radio is in service [2]. To be able to implement SDR a platform is needed. A plethora of platforms and applications can be chosen such as Cubic SDR, GQRX, SDR Sharp, GNU Radio and other. Between those GNU Radio is chosen because it offer great modality and allows for a more precise settings and options. This platform is based on programmable blocks that mimic associated hardware features, the block are created using Python or C++, this is a very important feature because it allows to create new block. Firstly designed for Linux, GNU Radio now can be used in various devices such as Raspberry Pi and other Operating systems such as windows using the GNU Radio Companion expansion.

II. QO-100

Es'hail 2 or QO-100 is a geostationary satellite that carries amateur radio transponders. Its main is to provide communication between radio amateurs from Brazil to Thailand. In the future it also wants to provide digital television to the Qatar and surrounding region. The satellite has incorporated two "Phase 4" amateur radio transponders, one narrow-band and one wide-band, they both operate in the 2400 MHz for uplink and 10450 MHz for downlink bands. As it was stated the satellite also carries a 8 MHz bandwidth transponder for experimental digital modulation schemes and DVB amateur television [3]. With more relevance to this project the QO-100 carries two beacons: one for radio amateur communications using SSB and another for a multimedia beacon using 8 APSK modulation, these two will be the focus of this project.

A. SSB

Single Sideband (SSB) signals are a type of amplitude modulation (AM) technique used in radio communication. Unlike traditional AM signals, SSB signals are more efficient in



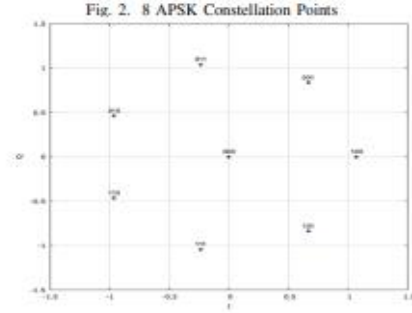
terms of bandwidth and power usage, making them popular in long-distance and high-frequency (HF) radio communication. This type of signal as the name implies utilizes only one of the two AM sidebands [4]. This gives the signal a smaller bandwidth, using in average less power in the transmission of the signal, this is favorable to satellite communications or other communication through high distance.

B. 8 APSK

APSK stands for Amplitude Phase-Shift Keying, and it is a type of modulation scheme used in digital communication systems. APSK is a hybrid modulation scheme that combines elements of amplitude modulation (AM) and phase-shift keying (PSK) to efficiently transmit data over a communication channel. The advantages of APSK modulation has over other type of modulations include spectral robustness and spectral and power efficiency. In terms of spectral efficiency, APSK modulation can achieve higher data rates compared to traditional modulation schemes by efficiently utilizing both amplitude and phase variations [5]. 8-APSK constellation diagram typically arranges the points in two rings, one inner ring, and one outer ring. The inner ring can consist of 1 up to 4 points, the outer ring consists of 4 to 7 points. in this instance the project will need to have an outer ring with seven points and one point in the middle to have compatibility with the signal coming from the multimedia beacon. the expression that gives these points is :

$$X = \begin{cases} r_1 e^{j\phi_1 + \frac{2\pi}{n_1}k} & \text{when } k \text{ is greater than } 1 \\ 0 + 0j & \text{when } k \text{ is } 1 \end{cases}$$

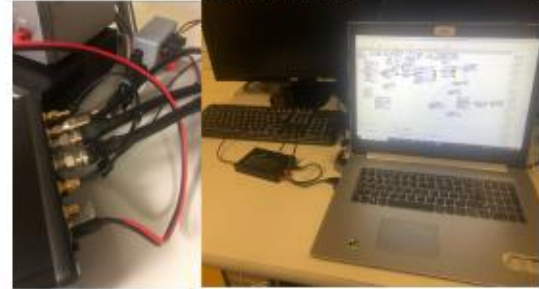
r represents the radius of the outer circle, φ the angle of the phase and n the number of point in the ring.



III. GROUNDSTATION

With the groundwork now laid, we begin the construction of a ground station where we could receive the signal from the QO-100. The foremost object in the ground-station is the antenna which has 1.8m in diameter, this antenna is fixed to ground pointing at the patch of the sky in which the QO-100 is present. After being received by the antenna, the signal with center frequency in the 10489 MHz, passes through a LNA that down-converts the signal to a more manageable 739 MHz. The signal passes through a coaxial cable to a Hack RF One and then to the CPU where the SDR receiver is running. There is also an optional component in the groundstation which is a DX Patrol, this equipment sintonizes the signal and further downconverts the signal to RF frequency of 432.5 MHz.

Fig. 3. Groundstation



IV. RECEIVERS

With the groundstation we can start working in the construction and designed of the receivers. The SSB and Multimedia receivers could be conjoined but for better understating they will be separate.

A. Multimedia Beacon Receiver

Between the two receivers, this receiver is the most complex. it comprised of two main parts: the demodulator and decoding parts. First we will state the variables that composed both part of this receiver.

1) *Variables*: The variables set will include the sample rate, constellation of the modulation, rcc taps, sample per seconds, offset frequencies, symbol map and symbol points. The sampling rate has a minimum value of 2MHz because of the limit thrust upon it by the Hack RF One. the constellation variable will need two parameter to fill it, constellation points, given by II-B equation and sym map which will correspond to the points given by that equation. The offset frequency is the variable which permits to search the beacon sounds to. Finally, the rcc taps will be of great value at the Symbol Sync block to filter out all the noise of the signals before they get matched.

2) *Demodulator*: In the multimedia beacon receiver the demodulator is the mass of components that receives the signal and then demodulates the frequency. First the signal is received by the the RTL-SDR block, this block receives the signal from Hack RF One and give it gain. the signal then passes through a FIR Filter, this filter cancels out the noise and then performs a frequency translation to put the signal at center. The RMS AGC is a component that normalizes the signal so the further demodulation and decoder could be made easier. the most import block of the demodulator is the symbols sync, this blocks matches the symbol to the samples allowing down the line the signal to be decoded. in this block the signal is decimated, interpolated and passes through the rcc taps. The final component in the demodulator is the 8 APSK Costas Loop, this block will phase lock the signal so that the constellation could be made available for decoding.

3) *Decoder*: The decoder section of the receiver is where the bits will be transformed to information sent by the QO-100. The first component of the decoder is the constellation decoder, this block only has the one parameter the constellation variable. After the constellation decoder the bits are grouped into GNU Radio designed messages (PDU) in the Sync and Create Packet PDU block. These messages are passed through an Reed-Solomon Decoder and then validated in the CRC Block. Finally the the file receiver saves the multimedia file into the CPU.

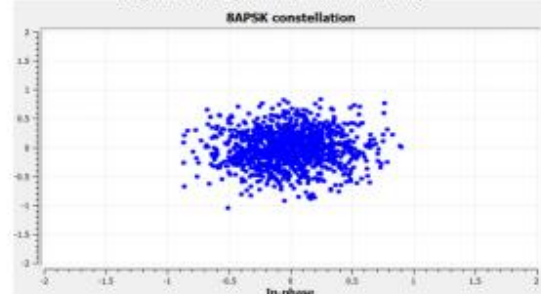
B. SSB Receiver

Comparing with Multimedia Beacon receiver this one is simpler as the modulation of the signal is not that complex. The signal itself originates or is received from the RTL-SDR source block with the almost the same parameters as in the multimedia beacon receiver. The first block the signal passe after being received is the DC blocker. The second block, Frequency Xlating FIR Filter is where the signal is filtered its frequency centralized and the noise filtered. To demodulate, the signal coming through the AGC2 block is separated into its real and imaginary compacts which in turn are multiplied to reach all the band and then joined again.

V. RESULTS

The results where divided according with the condition, with or without DX Patrol.

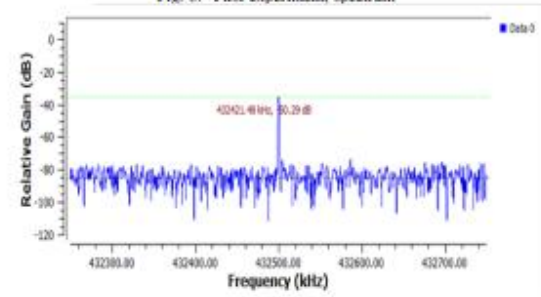
Fig. 4. First experiment, Constellation map



A. Without DX Patrol

1) *Multimedia beacon receiver* : as seen in figure the constellation only show noise

Fig. 5. First experiment, spectrum



In the the figure we see just a spike. as the the constellation figure only shows noise it seems safe to assume that the response in the frequency or beacon of the Hack RF One.

2) *SSB receiver* : when ran the SSB receiver hears no sound and in the spectrum only the response of the Hack RF One is visible.

B. With DX Patrol

When added the results with DX Patrol are as follows:

1) *SSB receiver* : An audio will also appear from the audio sink block. As the audio appears we first need to identify the beacon, using the variable offset. In this first attempt besides the sound of the beacon, no other sound was heard, so the variable controlling the RF gain was increased to 50 dBs. As the beacon was heard this is indeed strange. To further increase the gain the variables to change are the IF Gain and BB Gain. These variables have a working maximum value of 30 dBs, but if want to hear the voice communications the gain needs to be at least 50 dBs.

but thanks to that increase of gain the the console output shows the indication of overflow.

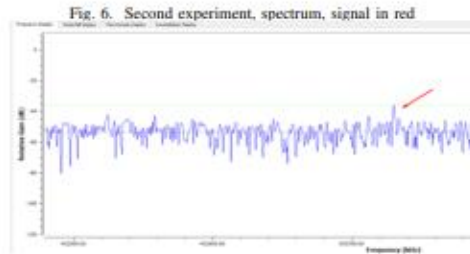


Fig. 6. Second experiment, spectrum, signal in red

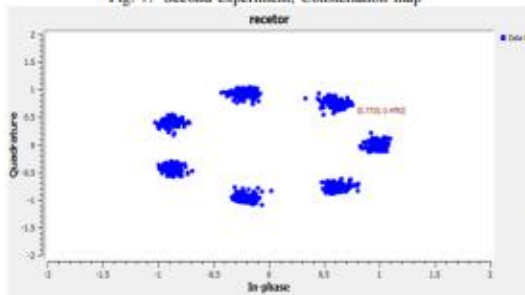


Fig. 7. Second experiment, Constellation map

2) *Multimedia beacon receiver* : When ran with DX Patrol the constellation map appears to show the 8 APSK modulation but missing a symbol.

If we tried to increase the gain as in the SSB receiver the results shows a distorted constellation with the missing symbol threatening to appear.

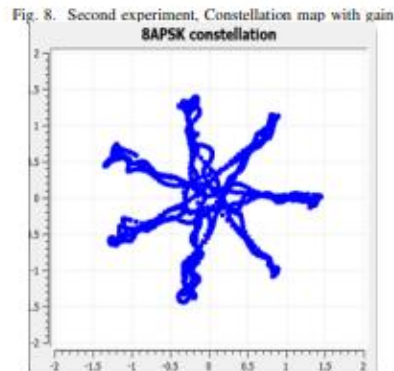


Fig. 8. Second experiment, Constellation map with gain

C. Correcting the missing symbol

When tried to increase the gain the missing symbol seem to almost appear, but with the gain already causing an overflow that is impossible. When with the help of a SDR application (Cubic SDR) shows that the QO-100 signal has lack of power.

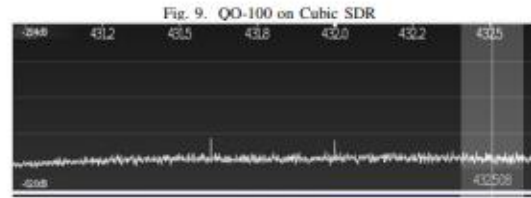


Fig. 9. QO-100 on Cubic SDR

To try to correct-it new drives for SDR were installed, a new Costas Loop in python was created by the results were the same. With the same results the best mean value of SDR were 12.569 dBs

VI. CONCLUSION

Through analysis of the results, it appears that the experiment without the DX Patrol failed to provide meaningful results. The multimedia receiver didn't receive any file and the SSB receiver failed to capture any sound apart from noise. The signal received didn't appear and only the response in frequency of the Hack RF One was visible. In the experiment that used DX Patrol results were achieved. The SSB receiver at first only produced noise, but with a large increased in gain it was able to receive SSB communication occurring around the globe passing through the QO-100. The multimedia receiver was also able to receive a file, that file was missing information, this is due to a decoding error in the receiver, the symbol representing zero was missing. AN increase of gain also was unable to solve it. As seen in the previous chapter the problem seems to be the lack of power of the signal. That lack of power can't be from the signal coming from space since it was stated in this project that that had no consequential effect, the lack of power then must belong to the coaxial cable.

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